



**Intuitive Psychology and Intuitive Physics: A  
Comparison of Understanding Between Children  
on the Autistic Spectrum and Typically  
Developing Children**

**Lynne M Binnie**

**PhD**

**The University of Edinburgh**

**2002**



## **DECLARATION**

This thesis has been composed by me and is entirely my own work. Publications arising from this thesis are included in the appendices. The joint author and the publishers of these publications have granted permission for their inclusion.

Lynne M. Binnie



## ACKNOWLEDGMENTS

First and foremost I would like to acknowledge and thank the children who participated in this research as well as the many schools who opened their doors to me and the numerous teachers who kindly allowed me into their class. Without this help the studies reported in this thesis would have been impossible. Special mention must be given to the Scottish Down Syndrome Association and the Lothian Autistic Society who offered me valuable advice and allowed me to contact their members.

I am very grateful to my supervisors Dr Jo Williams and Professor Jennifer Wishart for their guidance and support. As well as being the catalyst for my interest in child development Jo has also taught me the value in always having time for people, she has encouraged me to develop valuable skills as a researcher and has even given me the confidence to deal with reviewer's comments! Jennifer has taught me never to overlook the basic principles learned as an undergraduate and has also kicked my use of commas and apostrophes into shape! Their time, patience and effort have been very much appreciated.

Thanks must also go to the many individuals who advised, guided and supported me through my time at the University of Edinburgh. Special mention must be given to Lesley and Diana who listened to all my worries, always providing a shoulder to cry on as well as cakes to cheer me up! I would never have enjoyed myself as much during the past three years without your friendship and I will truly miss you now that it's over.

This thesis is dedicated to Scott who gave me the push to get started and the motivation to get finished. He kept me focused on the important things in life and for that I will always be grateful.

## ABSTRACT OF THESIS

This thesis considers how a disassociation among children with autism in cognitive functioning in the domains of psychology and physics might enhance our understanding of cognitive development in general. Cognition is assumed by many theorists to develop in a domain-specific fashion. This position holds that children's intuitive understanding is constructed differently according to the domain of knowledge. A literature review is reported which indicates that autism could indeed be a paradigm case for investigating this theoretical perspective.

Study 1 investigated intuitive concepts of psychology, physics and biology by administering two tasks from each domain to 23 typically developing pre-schoolers, 20 children with autism and 18 children with Down syndrome. Results found that children with autism performed significantly below the other groups on the intuitive psychology tasks. However, performance within the domains of physics and biology did not significantly differ across groups. This disassociated understanding evidenced between the domains of psychology and physics/biology in children with autism strengthens the argument that cognition develops domain-specifically.

Study 2 focussed in greater detail on this disassociation by employing three tasks each comprising a psychological and physical condition to 21 children with autism and three groups of typically developing children: 21 matched according to chronological age [CA]; 17 pre-schoolers; 18 seven-year-olds and 17 ten-year-olds. In both conditions of a picture-sequencing task children with autism were more likely to choose a physical causal picture than a psychological one to complete the sequence. This finding indicates that children with autism may prefer to reason about causality in a purely physical way. In a categorisation task no group differences were identified in the psychological condition. However, in the physics condition, children with autism and ten-year-olds were more likely to categorise according to physical features than superficial features. In a multiple-choice task, children with autism performed poorer than all other typically developing groups in the psychology condition but better than all comparison groups except the ten-year-olds in the physics condition. This study not only confirms initial findings but additionally demonstrates a superior ability to reason about

physical phenomena in children with autism. The theoretical and practical implications of this potential cognitive strength are discussed.

To investigate the nature of physical understanding in more depth, Study 3 compared both the predictions and explanations offered by ten children with Asperger syndrome and a CA matched group of typically developing children in respect to four physical concepts: floating/sinking; balance; trajectory; and vertical movement. Groups did not differ in the predictions offered in relation to each physical concept. However, significant group differences in the level of understanding evident in the explanations used to support their predictions were identified in two concepts: the CA matched children offered more advance explanations in the floating/sinking and balance tasks. Overall this study found that children with Asperger syndrome are very capable of offering predictions and explanations with respect to physical phenomena but their understanding was not superior to typically developing children of the same age. This study concludes that children with Asperger syndrome have an intact domain of physics that allows them to evoke physical causal reasoning.

Together the three studies reported in this thesis provide evidence for the domain-specific account of cognitive development. A disassociated understanding was identified between intuitive psychology and physics among children on the autistic spectrum. Furthermore, this thesis concludes that children on the autistic spectrum have an intact domain of physics that allows them to reason successfully about physical phenomena.

# TABLE OF CONTENTS

Declaration	i
Acknowledgements	ii
Abstract of Thesis	iii-iv
Table of Contents	v-vii
List of Figures	vii
List of Tables	ix
<b>1. Childrens Cognitive Development: Theoretical Perspectives and the Challenge of Autism</b>	<b>1-28</b>
1.1. Aims of this Thesis	1
1.2. Introduction	2
1.3. Development from a Domain-general Perspective	2
1.4. Development from a Domain-specific Perspective	4
1.4.1. What is a Domain?	6
1.4.2. Are Domains Theoretical?	8
1.5. Domain-specific Accounts of Cognitive Development	9
1.6. Developmental Psychopathology	17
1.7. Autistic Spectrum Disorders	18
1.7.1. Diagnosis and Demographics	19
1.7.2. Symptoms	21
1.8. Cognitive Accounts of Autism	24
1.9. Outline of this Thesis	27
<b>2. Intuitive Psychology: Understanding in Typically Developing Children and Children on the Autistic Spectrum</b>	<b>29-54</b>
2.1. Aims of this Chapter	29
2.2. Introduction	29
2.3. Basic Building Blocks of Intuitive Psychology	31
2.4. Key Intuitive Psychology Concepts	34
2.4.1. Perception and Knowing	35
2.4.2. Desire	36
2.4.3. Belief	37
2.5. Later Developments in the Domain of Psychology	41
2.6. Summary	42
2.7. Intuitive Psychology in Children on the Autistic Spectrum	43
2.8. The Absence of Basic Building Blocks	44
2.9. The Absence of Key Intuitive Psychology Concepts	46
2.9.1. Perception and Knowing	47
2.9.2. Desire	47
2.9.3. Belief	48
2.10. Summary	50
2.11. Is the Domain of Psychology Theoretical?	51
2.12. Conclusions and Implications for this Thesis	53

<b>3.</b>	<b>Intuitive Physics: Understanding in Typically Developing Children and Children on the Autistic Spectrum</b>	<b>55-80</b>
3.1.	Aims of this Chapter	55
3.2.	Introduction	56
3.3.	Basic Building Blocks of Intuitive Physics	57
3.4.	Key Intuitive Physics Concepts	61
3.4.1.	Object Movement	61
3.4.2.	Object Properties	65
3.4.3.	How Things Work	67
3.5.	Summary	69
3.6.	Intuitive Physics in Children on the Autistic Spectrum	70
3.6.1.	Evidence for Intact Understanding of Intuitive Physics	71
3.7.	Summary	76
3.8.	Is the Domain of Physics Theoretical?	77
3.9.	Conclusions and Implications for this Thesis	79
<b>4.</b>	<b>Study 1: Intuitive Psychological, Physical and Biological Knowledge in Typically Developing Pre-schoolers, Children with Autism and Children with Down Syndrome</b>	<b>81-102</b>
4.1.	Aims of this Chapter	81
4.1.1.	An Overview of Intuitive Psychology, Physics and Biology	82
4.1.2.	Comparative Studies Across Domains	84
4.1.3.	The Present Study	85
4.2.	Method	86
4.2.1.	Participants	86
4.2.2.	Materials	87
4.2.3.	Procedure	91
4.3.	Results	91
4.3.1.	Intuitive Psychology	91
4.3.2.	Intuitive Physics	93
4.3.3.	Intuitive Biology	95
4.4.	Discussion	97
4.4.1.	Conclusions	101
<b>5.</b>	<b>Study 2: Intuitive Psychology and Physics in Typically Developing Children and Children on the Autistic Spectrum</b>	<b>103-119</b>
5.1.	Aims of this Chapter	103
5.1.1.	An Overview of Intuitive Psychology and Physics	103
5.1.2.	The Present Study	105
5.2.	Method	106
5.2.1.	Participants	106
5.2.2.	Materials	107
5.2.3.	Procedure	110
5.3.	Results	111
5.3.1.	Preliminary Analysis of PIQ	111

5.3.2. Task Analyses	111
5.4. Discussion	116
5.4.1. Conclusions	118
 <b>6. Study 3: Understanding of Physical Phenomena in Children with Asperger Syndrome: An Investigation of Causal Predictions and Explanations</b>	 <b>120-146</b>
6.1. Aims of this Chapter	120
6.1.1. Childrens' Explanations	121
6.1.2. The Investigation of Theoretical Knowledge	123
6.1.3. The Present Study	124
6.2. Method	126
6.2.1. Participants	126
6.2.2. Materials and Coding Schemes	127
6.2.3. Procedure	131
6.3. Results	131
6.3.1. Analysis of Co-variants	132
6.3.2. Analysis of Tasks	132
6.4. Discussion	140
6.4.1. Conclusions	145
 <b>7. General Discussion</b>	 <b>147-163</b>
7.1. Aims of this Thesis	147
7.2. Theoretical Implications: Evidence for Domain-specific Cognition	148
7.3. Comparisons of Intuitive Physics and Psychology	150
7.4. The Status of Intuitive Physics Knowledge: Domains and Theories	153
7.5. Superior Intuitive Physics in Children on the Autistic Spectrum	156
7.6. Limitations of this Thesis and Suggestions for Future Research	158
7.7. Educational Implications	161
7.8. Summary and Concluding Comments	162
 <b>References</b>	
 <b>Appendices</b>	
A Ethical issues when conducting research with children	
B Study 2: The content of the eight stories in the picture-sequencing task	
C Study 2: Examples of categorisation stimuli from both psychological and physical conditions	
D Study 2: Multiple-choice workbook	
E Publications	

## LIST OF FIGURES

4.1	Percentage of children in each group who passed each psychology task	93
4.2	Percentage of children in each group who passed each physics task	94
4.3	Percentage of children in each group applying different rules to answer the balance task	95
4.4	Percentage of children in each group who passed each biology task	96
4.5	Percentage of children in each group applying different rules to answer the illness task	97
5.1	Mean performance of all five groups on both conditions of the picture-sequencing task	112
5.2	Mean performance of all five groups on both conditions of the categorisation task	114
5.3	Adjusted mean performance (maximum score = 12) with PIQ controlled in all five groups on both conditions of the multiple-choice task	115



## LIST OF TABLES

4.1	Number [N], mean CA, mean RV scores and associated ranges (years; months) of each diagnostic group participating in Study 1	86
4.2	Mean performance scores for each task across participant groups	92
5.1	Number [N] of participants, mean CA, mean PIQ scores and associated ranges (years; months) of the diagnostic groups participating in Study 2 and the mean RV score and range (years; months) of the participants with autism	107
5.2	Classes of phenomena employed in each condition of the multiple-choice task	110
6.1	Number [N] of participants, mean CA (years; months), mean IQ, PIQ and VIQ scores and associated ranges of each group participating in Study 3	126
6.2	Number of participants predicting both exemplars incorrectly [0] and number predicting one [1] and two [2] exemplars correctly for each variable in the floating/sinking task	133
6.3	Number of explanations provided as a function of level across all 8 exemplars in the floating/sinking task	134
6.4	Number of participants predicting both exemplars incorrectly [0] and number predicting one [1] and two [2] exemplars correctly for each variable in the balance task	135
6.5	Number of explanations provided as a function of level across all 8 exemplars in the balance task	136
6.6	Number of participants predicting four exemplars incorrectly [0] and number predicting one [1], two [2], three [3] and four [4] exemplars correctly for each variable in the trajectory task	136
6.7	Number of predictions given as a function of level across all 8 exemplars in the trajectory task	137
6.8	Number of explanations provided as a function of level across all 8 exemplars in the trajectory task	138
6.9	Number of participants predicting four exemplars incorrectly [0] and number predicting one [1], two [2], three [3] and four [4] exemplars correctly for each variable in the vertical movement task	139
6.10	Number of explanations provided as a function of level across all 8 exemplars in the vertical movement task	140



# CHAPTER 1

## CHILDREN'S COGNITIVE DEVELOPMENT: THEORETICAL PERSPECTIVES AND THE CHALLENGE OF AUTISM

### 1.1. Aims of this Thesis

This thesis will argue that children on the autistic spectrum provide an ideal paradigm for the investigation of domain-general and domain-specific theoretical accounts of cognitive development. In keeping with this position, the motivation of this thesis is twofold. Firstly, it aims to examine the evidence used to argue that children on the autistic spectrum lack an understanding of phenomena pertaining to the domain of psychology. Secondly, this thesis will investigate the relative strength of this group in reasoning about physical phenomena. By examining the evidence of dissociation in cognitive functioning between the domains of psychology and physics, arguably present in children on the autistic spectrum, an understanding of the structure of cognitive development among typical and atypical children may be enhanced.

Within current theoretical accounts of cognitive development there is a dichotomy between advocates of domain-general and domain-specific processes. Despite this, the developmental picture regarding typical development is becoming clearer and recently, the accumulating methods and theories have been applied to atypical populations. This area of work has been described as 'developmental psychopathology' and the strength of this paradigm is that both contributing fields can complement and enhance knowledge of each other. Activity in this area has been particularly prolific with regard to autism. In the latter sections of this chapter, the symptoms associated with a diagnosis of autism will be described. Presently there are a number of different cognitive accounts that lay claims to this condition and these will be discussed with respect to domain-specific and domain-general reasoning. It will be argued that the impairment among children with autism in understanding psychological phenomena (to be discussed further in Chapter 2) coupled with an intact ability to reason about physical phenomena (to be discussed in Chapter 3), may offer a fruitful avenue to investigate the dichotomy between domain-general and domain-specific cognitive processes further.

## **1.2. Introduction**

Over the past 20 years, a challenge to the widely held view that the human mind develops according to domain-general principles has developed across many disciplines including psychology, anthropology and linguistics (Hirschfeld & Gelman, 1994). The emerging view is that humans simply could not come to understand what they do in a purely domain-neutral fashion. Within developmental psychology, discontentment with general learning theories, as well as the impact of Fodor's 1983 book *'The Modularity of Mind'*, have led many researchers to approach cognitive development as domain-specific. Whereas before, cognition was thought to bring to bear general problem solving abilities spanning all areas of knowledge, newer approaches suggest that cognition is innately specialised to deal with specific types of information (Wellman & Gelman, 1992). As will become evident, domain-general accounts propose that knowledge acquisition grows and advances simultaneously across all subject areas as a result of changes in general cognitive architecture. In contrast, advocates of domain-specificity argue that several foundational areas of understanding develop independently from one another as a result of changes within the knowledge area itself. It will be demonstrated that current theorists do not position themselves at the extreme ends of this dichotomy; most include some domain-general and domain-specific development in their theoretical accounts.

## **1.3. Development from a Domain-general Perspective**

Predominant views of child development used to advocate that a few general learning mechanisms accounted for children's understanding across all areas of cognition. This position was founded largely on the work of Piaget (1932; 1952) who described the child as progressing through various stages in their thinking. According to his 'general stage' theory the child's developmental pathway corresponds to across the board transformations in the structure of their cognition. He advocated that at any point in time, the same underlying structures underpin thinking across all subject areas. For example, a child in the 'pre-operational' stage of development would demonstrate egocentrism in relation to all situations and all phenomena.

Karmiloff-Smith (1992) points out that adherence to domain-general processes is also evident in the work of the behaviourist movement influential in the 1950s. They proposed that an inherited physiological sensory system and a complex set of 'laws of

association' were all that was needed to account for behaviour and learning (Miller, 1989; Skinner, 1985). As a result, proponents of this approach reduced the acquisition and development of knowledge across all areas of understanding to these principles. Even more recent theories of development, such as the information processing approaches have characterised cognition as involving domain-general processes (Gilhooly, 1995; Vera & Simon, 1994). According to this stance, development across all areas of knowledge is a result of increased efficiency in computational processes such as 'encoding', 'comparing', 'combining' and so forth. For example, Kail (1990) argues that the child's information processing capacity increases as a result of hard-wired maturational changes in the brain and it is this that accounts for increasing cognitive ability, since the child can now hold in mind and think about more things at once.

Evidence from three main strands of research has begun to highlight the inadequacies of domain-general theories. Firstly, a wealth of research reported that failure on Piagetian tasks may not be the result of underlying cognition, but may reflect children's attempts to make 'human sense' of the experimental situation (Donaldson, 1979). To overcome these problems, new research paradigms were designed to reduce 'experimenter effects' and remove the necessity for verbal responses. As a result, many key abilities have been demonstrated in children at much younger ages than previously envisaged on the basis of Piaget's developmental stage model (see Brown, Metz & Campione, 1996). Moreover, this work showed that knowledge develops differently according to the particular area under scrutiny. For example, it has been shown that contrary to Piaget's theory, concrete operations (such as conservation and transitivity) do not appear at the same age across all knowledge areas (Chapman, 1988).

Secondly, there has been a shift in emphasis from investigating the forward progression of children's abilities to employing new methodological tools such as 'habituation/dis-habituation' and 'preferential looking/listening' in order to investigate earlier competencies in very young infants. Results have shown that in contrast to Piaget's claims, "infants are far more cognitively advanced than was previously dreamt of" (Richardson, 1998; p2). For example, two-day-old infants appear to have an inherent conception of what an object is (Kellman & Spelke, 1983) and can imitate basic actions such as tongue protrusion (Meltzoff & Moore, 1983). This work has renewed convictions about the genetic preparedness of the human infant. Additionally, it has

been suggested that infants have specific constraints on learning that direct attention to certain stimuli before others, thereby lending support to alternative theories of domain-specificity in cognitive development (Gelman, 1990).

Finally, many studies have started to investigate the developmental pathways of atypical populations. This area of research focuses on the mutually informative relationship between studying typically developing children and atypically developing children (Burack, Charman, Yirmiya & Zelazo, 2001). It has been shown that among atypical children reasoning in different areas may develop in a somewhat independent way, in that contrary to the position held by domain-general theories, their abilities in one domain of knowledge do not always reflect abilities in another. For example, Petersen and Siegal (1998) compared understanding of basic physics, biology and psychology concepts in children with autism, children who were deaf and average pre-school children and found systematic differences between the groups on tasks pertaining to the domain of psychology (this will be discussed further in Chapter 4). Taken together, these three research trends have given weight to feelings of discontentment with traditional domain-general theories of cognitive development.

#### **1.4. Development from a Domain-specific Perspective**

Theorists of domain-specificity argue that many cognitive abilities are specialised to deal with specific content areas (Hirschfeld & Gelman, 1994). Proponents of this approach have likened the mind to a Swiss army knife, conceiving it as constituting a bundle of functionally specialised neural circuits (i.e. domains), evolved to deal with evolutionary adaptive problems (Cosmides & Tooby, 1994; Cosmides, 1997). It must be noted that specific domains of knowledge are not formed arbitrarily. Instead, research indicates that well organised content areas may develop in a biologically natural way. The most recognised of these 'natural' domains is language and it was the characteristics pertaining to this area that led the linguist Chomsky to develop the first modern account of domain-specificity. Chomsky (1980; 1988) argued that the properties of the language faculty are unique, reflect our individual biological endowment and cannot be attributed to a general set of reasoning abilities. This is perhaps the most widely known domain-specific argument and has been expanded by various researchers looking for similarities in other 'natural' knowledge areas. For example,



Marr's computational theory of vision is based on domain-specificity (Marr, 1982) as is Liberman's theory of auditory processing (Liberman & Mattingly, 1989).

The trend towards characterising child development as domain-specific has led to a wealth of research into what children know and do not know about the world. Many researchers have been influenced by the fact that our external world can be understood with reference to psychological, physical and biological phenomena (among others, Inagaki & Hatano, 2002; Wellman & Gelman, 1992; Wellman & Inagaki, 1997a) and have concentrated their efforts on investigating these three domains of knowledge in young children. These areas are thought to encompass the major domains of understanding in humans and are represented by intuitive understandings encompassing phenomena such as persons and their mental life, plants and animals and their characteristics, and physical objects and their movement (Inagaki & Hatano, 2002). A wealth of research documents that young children are very able to make firm distinctions between and among these three areas of knowledge prior to formal education (Carey, 1985; Wellman & Gelman, 1992; Wellman & Inagaki, 1997b). Further, it has been suggested that this knowledge may have some innate underpinnings. This stance contrasts with earlier assumptions of child cognition: "Neither the Piagetian nor the behaviourist theory grants the infant any innate structures or domain-specific knowledge" (Karmiloff-Smith, 1992; p7).

It is a measure of how far we have progressed, that today, a substantial proportion of contemporary developmentalists do not see cognitive development being general or stage-like as Piaget and the rest of the field once thought (Flavell, 2000). However, disagreement reigns over just how general or specific cognitive development processes are. Many conclude that for cognition to operate effectively some general learning mechanisms must be present (Richardson, 1998) and, as will be demonstrated, most domain-specific accounts of child development grant the co-existence of domain-general processes.

*Indeed for it (i.e. cognition) not to have any general stage properties at all would seem counterintuitive: an extreme 'unrelated mindlets' view does not seem to me any more likely to be right than Piaget's 'grand stage' view.*

Flavell, 2000; p14

Although the area of work to be focused on in this thesis seems extremely promising there are still many key issues that remain to be resolved. For example, there is as yet no agreed definition of what constitutes a 'domain'. Likewise, each individual theorist has his/her own position regarding what is and what is not 'theoretical knowledge' and often differ as to when they grant this property to children's understanding. Moreover, only recently have questions been asked about atypically developing children's understanding and whether this too is structured in terms of domains and intuitive theories.

Despite these outstanding issues many researchers, stressing the importance of developmental data, have tried to explore the child's initial conceptual state and how this changes throughout childhood. Before the findings from these developmental studies are introduced this chapter will first consider the various definitions and characteristics applied to a 'domain' and a 'theory' by different theorists. An understanding of these basic assumptions is pertinent to the discussion of domain-specific accounts of cognitive development that will subsequently be presented in this thesis.

#### **1.4.1. What is a Domain?**

In spite of the wealth of research in the field of domain-specific cognition there is no agreement as to the exact conceptualisation of a domain: "It is easier to think of examples of a domain than to give a definition of one" (Hirschfeld & Gelman, 1994; p20). That being said, it has been argued that to credit young children with specific domains of knowledge they must use the independent principles of the domain in question to produce "coherent bodies of knowledge that involve causal explanatory understanding" (Hatano & Inagaki, 1994; p120). In order for this characterisation to be workable, most proponents of domain-specificity suggest that a domain must encompass mechanisms for singling out appropriate entities that belong to the domain i.e. they appeal for the presence of constraints. Without constraints, domain-specific reasoning could not proceed. For example, an advanced system of knowledge about human behaviour is useless unless one can determine when he or she is faced with a person in order to apply psychological reasoning in an appropriately constrained way i.e. constraints are more than just an ontological device.

It is not thought that constraints grant children with specific knowledge. Instead it is suggested that they operate within a domain in such a way as to “restrict the range of hypothesis space to be explored” in order to direct the child’s attention to the particular phenomena in question (Hatano, 1997; p75). The appeal towards constraints is by no means straightforward. Keil (1981) points out that constraints could be considered as being in the learner or outside the learner. Even if we focus on those in the learner, there remains little agreement as to whether they are innate or acquired, probabilistic or absolute, regarding processes or structures, domain-specific or domain-general. However, Keil (1991) claims that the evidence supports the presence of domain-specific innate constraints (environmentally insensitive knowledge structures) and he also concludes that the presence of domain-specific acquired constraints (environmentally sensitive knowledge structures) seems inevitable.

It has been argued that if autonomous domains of understanding are to be taken seriously, a domain must encompass a set of phenomena, ontological commitments and causal mechanisms that offer explanations and predictions about relevant phenomena within the domain (Carey, 1985; 1995). These principles enable young children not only to recognise phenomena as relating to a particular domain but also allows them to induce a basic form of reasoning pertaining to it (Hatano, 1997).

Within developmental psychology five differing notions of a domain can be found. One is of particular importance to this thesis in that it proposes that a domain can be regarded in terms of “naïve theories that carve phenomena into differing systems of knowledge and belief” (Wellman & Gelman, 1992; p340). In keeping with this definition, Wellman and Gelman (1992) argue for the presence of three domains, namely psychology, physics and biology. They view a domain as constituting an overarching framework theory that defines the domain in terms of content area and allows the child to acquire relevant knowledge or as they describe ‘specific theories’. In a similar way, Karmiloff-Smith (1992) thinks of a domain as an ‘umbrella’ term for a collection of corresponding micro-domains. She views a micro-domain as a ‘set of representations’ that sustains a specific area of knowledge such as gravity within the domain of physics.

This thesis will not argue that any one definition of domain is correct and although most theorists articulate their definition of a domain in very different ways, there are a few recurring properties. For the purpose of this thesis it is suffice to support the commonly-held view (see Carey, 1985; Gopnik & Meltzoff, 1997; Hirschfeld & Gelman, 1994) that a domain involves a set of causal explanatory mechanisms (e.g. principles or theories), a set of phenomena to which mechanisms are applied (i.e. ontology) and ontological commitments (i.e. rules of application of mechanisms). Moreover, it will be accepted that domains incorporate specific constraints. These function in order to promote the development of further understanding pertaining to the particular domain in question.

#### **1.4.2. Are Domains Theoretical?**

The issue of theoretical knowledge is a recurring theme throughout this thesis and is important because as well as being intrinsically constraining, many accounts of a domain convey the idea that it comprises a body of theoretical knowledge. In fact, domains are depicted as being responsible for organising children's knowledge into structures that are similar in nature to 'scientific' theories. The anthropologist Atran (1994) opposes this analogy and argues it is fundamentally misleading to describe cognition using the same terms as scientific thought. However, in the cognitive development literature, the term theory is often preceded by terms such as 'common-sense', 'folk', 'naïve', 'framework' and 'intuitive'. These definitions indicate the presence of characteristics distinct from the ones assigned to a scientific theory. On the one hand, 'intuitive' and 'scientific' theories have been described as "explanatory structures that characterise causal mechanisms at work in the world" (Carey, 1996; p190). However on the other, scientific theories are deemed to be the result of conscious, institutionalised activity, arising from structured scientific experiments. These characteristics are not attributable to intuitive theories and, as many have pointed out, these distinctions cannot be overlooked when dealing with this area of research (Gopnik & Wellman, 1994; Keil, 1994).

Intuitive theories are by definition domain-specific: biological theories concerning reproduction and genetics cannot be correctly applied to physical phenomena such as gravity. In addition, they make ontological commitments: they specify the type of phenomena that are included within the domain for example, a domain of biology



appeals to species and DNA whereas the physics domain appeals to quarks and masses (Hirschfeld & Gelman, 1994). Intuitive theories also provide a mode of explanation, for example, a physical theory of gravity will explain why if you throw a ball into the air it will fall to the ground. Further, underlying these characteristics of a theory is the principle of 'coherence' in that it is impossible to consider a theoretical concept in isolation because its definition is intertwined in a web of other concepts and terms. For example, an understanding of 'a planet' cannot be considered in isolation of concepts such as the solar system, comets and asteroids (see Wellman, 1990).

Theoretical knowledge is often discussed with respect to children's explicit and implicit understanding. Implicit understanding is characterised as being simple, perceptually grounded and shown via non-verbal behaviours. Explicit understanding is deemed more flexible and open to conscious awareness and as a result is more coherent and can be expressed verbally (see Keil, 1999). The distinction between these two types of knowledge has, for some, provided a boundary whereby implicit understanding is not seen as being theoretical (i.e. Karmiloff-Smith, 1992) however, others do not draw such a distinction and argue that both types of understanding can be given theoretical status (i.e. Gopnik & Meltzoff, 1997; Inagaki & Hatano, 2002).

The term theory has been used to describe a variety of conceptual understandings and, as with domains, there is no universally agreed definition. Theoretical knowledge is deemed to be embodied within a domain and in-keeping with this suggestion, this thesis will adhere to the description of a theory as being a coherent, well-organised system of explanatory beliefs that enable children to explain events and make predictions (Murphy & Medin, 1985; Wellman, 1990). Throughout the remainder of this chapter attempts will be made to identify and present each theorist's position with regard to theoretical knowledge.

### **1.5. Domain-specific Accounts of Cognitive Development**

The idea that children's understanding comprises of domains and theories is relatively new. As already alluded to, these definitions are intrinsically linked to the premise that cognition develops in a domain-specific fashion. It is important to note that domain-specific accounts of cognitive development are not homogeneous. It will be shown in the following section that they differ widely in the way in which they account for

development. For example the modular perspective, which will be dealt with first, views domain-specificity as implying that the child's cognitive architecture is pre-ordained before birth. Advocates of this position often concentrate on identifying specificity in the characteristics of the cognitive architecture regardless of knowledge area (e.g. Fodor, 1983; Leslie, 1994). Further, their 'nativist' perspective implies that knowledge is not accumulated and revised to accommodate environmental stimuli. As Gopnik and Meltzoff (1997) point out, modules are assumed to lead to predictions because they are designed to do so.

However, "considering development domain-specific does not necessarily imply modularity" (Karmiloff-Smith, 1992; p6) and accordingly, others do not see cognitive development as being so encapsulated. Although many acknowledge that initial building blocks may be innate, there is a general consensus that understanding can be changed and built upon by evidence (i.e. Carey, 1985; Gopnik & Meltzoff, 1997; Karmiloff-Smith, 1992; Keil, 1994). The work that will be examined subsequently in this chapter is concerned with these various domain-specific perspectives.

Modular accounts of cognitive development suggest that representations of the world enter the system in the form of symbols. These are analysed, stored, recalled etc. by genetically specified hardwired computational processes called modules (Richardson, 1998). Fodor (1983) greatly influenced this theoretical position. He argued that the architecture of the mind constituted a structured dichotomy between a domain-general central processing capacity and, domain-specific procedures that are at work in a wide variety of knowledge areas. Most of the interest in Fodor's theory was a result of his speculation that the inputs for central processing originate from genetically specified, independently functioning, special purpose modules. Fodor (1975) argues that these distinct modules receive unique information from the environment and, in turn, output data in a common representational format (the 'language of thought') that is suitable for central (domain-general) processing. According to Fodor (1983) each unique module is hardwired and encapsulated; thus information that is not specific to the module can neither influence nor have access to the module's internal workings. This results in modular processing being mandatory, fast and more importantly, insensitive to previous experience.

In keeping with the modular perspective, Leslie (1987; 1994) suggests that the child's information processing system is organised into an innate specified set of two modules that can crudely be described as governing the domains of 'physics' and 'psychology'. He views these modules as an integrated cognitive structure that revolves around a core notion of Agent i.e. animate object and Agency i.e. its enduring properties (Leslie & Roth, 1993; Leslie, 1994). The first of Leslie's hierarchical modules is named the 'Theory of Body Mechanism' (ToBy) which is activated around three-to-four months of age. ToBy distinguishes Agents from other physical bodies and accounts for the infant's rapid acquisition of knowledge about the non-intentional mechanical properties of objects and subsequent events i.e. intuitive physics. The second module is called the 'Theory of Mind Mechanism' (ToMM) and is concerned with the intentional properties of Agents. Its purpose is to represent 'meaning' and provides the child with an intuitive understanding of the mental states of Agents i.e. intuitive psychology. ToMM has two sub-components, the first to emerge is ToMM *system 1* that embodies knowledge about Agents and the goal-directed action they produce. It has the function of identifying the factors that play a role in what the Agent is acting (or trying to act) to bring about. According to Leslie (1994), this module emerges in development at around six-eight months. Succeeding this is ToMM *system 2*, this is concerned with the mental states of agents and the behaviours they produce. Its role is to relate an Agent's behaviour to their intentions by constructing a data structure named by Leslie and Roth (1993) as the 'M-representation' (or elsewhere as the meta-representation, see Leslie, 1994). ToMM *system 2* emerges around 18-to-24 months and is signalled with the emergence of intentional communication such as declarative pointing (Leslie & Roth, 1993) and then subsequently by the emergence of pretence in young children (Leslie, 1994).

Leslie (1994) does not speculate on the role of domain-general processes. He simply remarks that in the pre-school period general problem solving abilities are minimal. The main thrust of his work arises from his belief that the ToBy and ToMM comprise an important part of the core cognitive architecture and account for development, rather than being a product of its outcome. He argues that each module corresponds to a separate independent subsystem that constitutes a specialised way of acquiring and organising information. He postulates that once the module emerges in development the information that it rapidly accumulates is the basis for all subsequent conceptual



understanding. As a result, a theory of bodies (i.e. intuitive physics) and a theory of mind (i.e. intuitive psychology) are acquired rapidly without much deliberation.

Modular accounts of development are very restrictive and, although many give consideration to domain-general development, few allow for the process of development within a module (Karmiloff-Smith, 1992). For example, although Leslie (1994) acknowledges that conceptual change does occur in children's representation of the mind he attributes it to the activation of ToMM *system 2*. Likewise, there is no room for development in Fodor's theory, he describes the internal workings of modules as being genetically specified at birth and very inflexible. Further, he argues that these structures do not change throughout development and, that superficial performance problems are to blame for a young child's poor performance on some tasks in comparison to an older child (Fodor, 1992). According to these modular accounts, children's understanding develops as a result of non-conceptual changes in information processing. This is not achieved through a process of reorganisation or change but is simply an improvement of core cognitive capabilities that are present from birth.

Karmiloff-Smith (1992; 1999) acknowledges the strengths of modularity but takes a much more developmental perspective. She dismisses the view of pre-prescribed modules in favour of what she calls a process of 'modularization' that occurs as a product of development. This view takes account of the plasticity of early brain configuration and suggests that subsequent development allow brain circuits to be selected for domain-specific computations. This view speculates that there are domain-specific predispositions present from birth that channel and constrain the infant's attention to relevant environment input (Karmiloff-Smith et al., 1993). As well as these innate predispositions to attend to certain stimuli, Karmiloff-Smith (1992) proposes that information is represented in the mind by one of four levels of representation. She describes these as: 1) Implicit [I] i.e. unconscious analysing and responding to stimuli; 2) Explicit-1 [E1] i.e. going beyond innate constraints but not conscious; 3) Explicit-2 [E2] i.e. conscious access without verbal report; and 4) Explicit-3 [E3] i.e. conscious access with verbal report.

Karmiloff-Smith (1992) argues that knowledge changes as a result of the human infant being equipped with an innate computational process that 're-describes' initial implicit

representations making them progressively more explicit. She calls this process 'representational re-description' [RR]. Although the process itself is domain-general, it is affected by the level of representation that is held by a domain at a particular point in time, that is, the global process of RR follows the same standard format but it occurs within domains (and micro-domains) at different points. This view of domain-general processing contrasts with Fodor's (1983) position. Whereas he sees domain-general processing as being concerned with an overall cognitive goal, Karmiloff-Smith views the domain-general process as operating independently in different knowledge areas thus adhering to the characteristics of domain-specificity. To be more precise, RR does not invoke simultaneous changes in knowledge across (micro) domains but involves only changes within (micro) domains. She asserts, "there is no such thing as a phase E2 child. The child's representations are in E2 format with respect to a given micro-domain" (Karmiloff-Smith, 1992; p25).

Karmiloff-Smith (1992) argues that the process of RR continues to operate within domains and micro-domains continually throughout development. This ongoing process is theory-driven and gradually allows the child to construct theories about the world. According to her RR model, young children's implicit representations cannot be described as 'theoretical'. Instead she insists that it is not until understanding can be demonstrated by the ability to combine successful inferences with verbal justifications that children can be described as being 'theorists'. She arrives at this conclusion because in her view to have a theory, knowledge must be encoded in a format that can be used outside normal input/output relations and this only occurs once knowledge shifts from being implicit to explicit i.e. from phase I to phase E2/3. The overriding assumption behind her position is that the dynamic dichotomy between the child's innate predispositions and the general process of RR allows the infant to progress developmentally. She speculates that this is how the human conceptual system becomes domain-specific.

In a similar vein to Karmiloff-Smith's innate predispositions, Keil (1994; 1995) suggests that the young infant has innate constraints that yield initial beliefs i.e. they get the infant started. Keil (1994) calls these innate skeletal constraints 'modes of construal' and suggests that they account for subsequent learning in the 'most belief-laden' aspects of cognition, i.e. the fundamental aspects of the world shared by all learners. Keil suggests

that prior to the development of fully-fledged theories, children's modes of construal produce general expectations and biases concerning the causal powers of properties. For example, he demonstrates that when young children are asked about previously unencountered phenomena, such as natural kinds, they hold biases for some causal mechanisms of explanation over others. Keil argues that these biases emerge from the way in which children's cognition is structured and although not initially theoretical, he does argue that they lead to the construction of theoretical knowledge and in 1991 he specifically describes these as 'theoretical biases'.

Like Karmiloff-Smith's process of RR, Keil (1994) proposes that modes of construal are not exclusively tailored to specific domains. Instead he suggests that they give rise to different sorts of explanation with regard to various sets of phenomena. As a result they create an early ontology and channel theory construction. For example, a 'teleological' mode of construal lets us decide (very quickly) if a novel entity is a living thing, an artefact, a non-living natural kind or a psychological entity. Subsequently all other properties are invoked in light of the initial decision, i.e. domain-specific theories are employed (Keil & Silberstein, 1998). For Keil (1995) modes of construal promote theory construction and consequently categorise input so that domain-specific operations can be carried out.

In Keil's (1995) view the young child is endowed with six or so causal explanatory biases (i.e. modes of construal) that emerge early in life and constrain conceptual growth across all areas of cognition. According to Keil, where the younger child and the older child differ is in their ability to use these biases but the basic modes of construal are present, and continue to constrain knowledge in the same way, across all ages. In this respect Keil's thesis is similar to the modular accounts dealt with earlier. He suggests that development is a product of enrichment that is, learning how to access and apply biases and constraints in different contexts rather than requiring any fundamental changes in their form and nature.

Whereas Keil (1995) argues that an innate set of structures constrain the way in which a child interacts with the world and this eventually leads to domain-specific areas of knowledge, others are in support of there being a more concentrated collection of constraints that operate, from the beginning, in a domain-specific manner. As already

mentioned, Wellman and Gelman (1988; 1992) assert that young children have three initial 'framework' theories pertaining to psychology, biology and physics respectively. They postulate that young children appeal to such a structure before showing detailed understanding of a particular topic or, as they suggest, a 'specific theory' (Wellman & Gelman, 1992). According to this position very early knowledge is 'theory-like' and, although this understanding is initially fragile, it becomes strengthened and consolidated within each domain as children become more consistent in their understanding. They assert that conceptual development, even in its initial stage, comprises the task of theory construction.

Another proponent of this position is Carey (1991; 1995). She argues for the existence of an innate domain-specific system of knowledge governing, from birth, the domains of physics, number and psychology. In 1995 she referred to these systems as 'framework theories' (taken from Wellman & Gelman, 1992) and suggests that they guide children's reasoning about world phenomena and can also be the basis for new framework theories to develop. According to Carey (1990; 1995) a framework theory (or as she sometimes calls it an 'intuitive theory') is a cognitive structure that guides perception and reasoning within a particular domain of knowledge. She conceptualises it as constituting a single independent knowledge system that is organised around a body of core (innate) principles, principles that constrain the way in which a child interacts with their environment. More specifically it is these principles that are responsible for defining the entities that are covered by a domain, as well as allowing reasoning about such entities to take place. Carey (1996) argues that innate framework theories form the basis for future cognitive development. They place the infant on the correct path towards appropriate knowledge acquisition but are soon overridden as the child interacts with his/her environment and becomes involved in the process of conceptual change. Conceptual change involves overriding core principles within a domain with new principles that are 'incommensurable' with the old. In turn these become the foundations for new framework and specific theories. Carey views the development of knowledge as sometimes involving a radical overhaul of the initial conceptions within a domain and accordingly, she argues that the theories held by older children and adults in our culture differ qualitatively.



Gopnik and colleagues (Gopnik & Meltzoff, 1997; Gopnik & Wellman, 1994) also posit that initial conceptual structures can undergo radical restructuring during the course of development. Their theoretical account of cognitive development asserts very forcefully that children's knowledge is theory-driven from the start. On the basis of this premise they have named their account 'theory theory'.

Gopnik and Meltzoff (1997) account for conceptual development by suggesting that at birth the child is equipped with a modular peripheral system and an innate collection of 'starting-state' theories. In 1997 they discuss three theories; a theory of appearances (i.e. physics), a theory of action (i.e. psychology) and a theory of kinds (i.e. object categories). Gopnik and Meltzoff see the make-up of a theory as including general constraints regarding an underlying causal structure of the world. However, unlike Keil's view of constraints, the constraints in this system are not static. This position asserts that new theories override old ones and thus constraints change; "as we learn more, we also learn new ways to learn" (Gopnik & Meltzoff, 1997; p44).

In addition to starting state theories, 'theory theory' lays claims to an innate (domain-general) theory making mechanism that revises initial theories on the basis of new evidence i.e. it is the mechanism for theory change (Gopnik, Capps & Meltzoff, 2000). According to this perspective, the domain-general theory change process yields a collection of facts that posses many regularities, however, this type of information is according to the authors, not theoretical and is instead referred to as 'empirical generalisations'. Empirical generalisations produce limited and shallow explanations i.e. piecemeal and context specific knowledge. It must be noted that Gopnik and Meltzoff (1997) state that cognitive development is best explained in terms of theory formation and not specifically in terms of this domain-general mechanism.

It is suggested that theory formation starts as a result of the accumulation of evidence that cannot be explained by the child's present theory (Gopnik & Meltzoff, 1997; Gopnik et al., 2000). At first children try to ignore counter evidence however, they eventually are forced into developing 'ad hoc auxiliary hypotheses' which are used until a new theory fully develops. Once the new theory is put into place, it is used in what Gopnik and Meltzoff call an "intense period of experimentation and/or observation" (1997; p40) and eventually the process of theory formation will start again.



Theory formation is a continual process and implies that the things that children know (or think they know) are always open to further revision (Gopnik, 2000). This process continues until the theory a child holds at a particular time can explain and predict a wide range of phenomena (Gopnik & Meltzoff, 1997; Gopnik et al., 2000). As a result “children are never in a dry dock; they never get a chance to construct their theories from scratch” (Gopnik & Meltzoff, 1997; p68).

According to theory theory, theory change starts almost immediately after birth and continues throughout the initial period of a child’s life. Additionally, it is argued that cognitive and semantic development within a domain are intrinsically linked. They conclude that in contrast to a strict modular theory “what seems more plausible is that evolution selected for a cognitive capacity to revise concepts on the basis of evidence, that is, a theory making ability” (Gopnik & Wellman, 1994; p284). Theories are considered to function in order to predict, interpret and explain a variety of evidence. Thus ‘theory theory’ grants young infants with very well equipped innate structures designed to promote conceptual development. Recently Gopnik (2001) has suggested that causal reasoning is the primary driving force for theory change and she attributes this to human evolutionary forces.

The preceding discussion illustrates that many researchers have considered children's knowledge acquisition as involving domain-specific rather than purely domain-general processes (e.g. Fodor, 1983; Karmiloff-Smith, 1992; Keil, 1999). The theoretical accounts presented differ in terms of how they characterise theoretical knowledge and as well as how they assign domain-general processes to children’s cognitive development. Nevertheless, they do support the claims that typically, children have innate principles, often evident implicitly during infancy, as well as explicit intuitive understandings (often described as theories) that constitute various domains of knowledge (Carey, 2001; Wellman & Inagaki, 1997a).

### **1.6. Developmental Psychopathology**

A number of domain-specific accounts regarding children’s cognitive development have been introduced. As already mentioned, this domain-specific research perspective has in some cases been extended to include atypical development. However, with respect to the work presented so far in this thesis, only the theoretical accounts of Leslie

(Leslie & Thaiss, 1992), Karmiloff-Smith (1992) and Gopnik et al. (Gopnik & Meltzoff, 1997; Gopnik et al., 2000) have been examined empirically in relation to the development of atypical development. These three positions differ widely in their capacity to encompass atypical developmental profiles and as a result make specific predictions about the ways in which anomalies may arise. In Chapters 2 and 3 the position of these three accounts of cognitive development will be given in relation to the development of understanding in the domains of intuitive psychology and physics in typically developing children and children on the autistic spectrum. The approach of studying both typical and atypical populations is often described as 'developmental psychopathology'. This paradigm is based on the assumption that "we can understand more about the normal functioning of an organism by studying its pathology, and, likewise more about its pathology by studying its normal condition" (Cicchetti, 1984; p1).

Within the field of developmental psychopathology, children with conditions such as autism, Down syndrome, Williams syndrome and Fragile-X have been studied alongside typically developing children. Findings have started to reveal stark comparisons in the continuity and discontinuity of development. In particular, the dual existence of strengths and weaknesses in knowledge areas in differing populations has been identified and linked to the manifestations of cognition. In fact, current theoretical perspectives of cognitive development are often judged on their ability to encompass evidence gathered from individuals with autism (Burack, et al., 2001). The symptoms of autism have proved a challenge to many mainstream accounts of cognitive development since they arguably demonstrate an impairment among children with autism in understanding psychological phenomena (see Chapter 2) coupled with a potentially intact ability to reason in other areas such as physics (to be discussed in Chapter 3). As this thesis will illustrate, this uneven developmental profile has been extensively related to domain-general and domain-specific theories of cognitive development (e.g. Karmiloff-Smith, 1992; Wellman & Gelman, 1992).

### **1.7. Autistic Spectrum Disorders**

The following section will focus on developmental patterns in children with autistic spectrum disorders. It briefly describes the demographics, symptoms and cognitive theories associated with the condition in order to argue that investigation into the

cognitive abilities of individuals with autism may potentially provide valuable insights into the strengths and weaknesses of current theories of cognitive development.

### **1.7.1. Diagnosis and Demographics**

Autism is an early emerging developmental syndrome with symptoms usually present before the age of three years (World Health Organisation [WHO], 1993). It manifests itself in a 'triad of impairments' in social interaction, communication and imagination (Wing & Gould, 1978), typically accompanied by a narrow and repetitive range of behaviours. Autism is a spectrum disorder that includes the syndromes originally described by Kanner (1943) and Asperger (1944, cited in Frith 1991), but is much wider than these two sub-groups. Clinicians and researchers in the field adhere to two internationally accepted diagnostic systems that incorporate the triad of impairments associated with autism as well as other common behaviours linked to the condition. These are the World Health Organisation's International Classification of Diseases now in its tenth edition [ICD-10] (WHO, 1993) and the American Psychiatric Association's Diagnostic and Statistical Manual now in its 4th edition [DSM-IV] (American Psychiatric Association [APA], 1994). However, autism is a very heterogeneous condition and diagnosis can be particularly difficult (Medical Research Council [MRC], 2001). Symptoms are presented in a wide variety of combinations, from mild to severe. A diagnosis on the severe end of the spectrum, often labelled 'low-functioning' autism, may take the form of highly unusual and aggressive behaviour accompanied by little or even no communicative speech. In its milder form individuals with autism are labelled 'high-functioning' and exhibit intellectual abilities in the normal range (i.e. IQ between 85-115) with only slight delays in language acquisition.

Individuals at the high end of the autistic spectrum are often described as having Asperger syndrome. It must be noted that although Asperger syndrome is classified as an autistic spectrum disorder it is often represented as a distinct sub-group with its own clinical profile (Gillberg, 1996). Asperger syndrome is recognised in current diagnostic criteria as similar to autism in terms of marked impairments in social communication but without any accompanying language or cognitive delay (APA, 1994; WHO, 1993). Despite this apparent separation from the autistic spectrum it must be accepted that no precise cut off points between autism and Asperger syndrome can be defined (Wing, 1981; 2000). There is considerable debate (e.g. Schopler, Mesibov &



Kunce, 1998) regarding whether Asperger syndrome reflects an altogether different condition to autism (as argued by Klin, Volkmar, Sparow, Cicchetti & Rourke, 1995) or whether it is simply a more mild variant of the same disorder (see Szatmari, Tuff, Finlayson, & Bartlucci, 1990; Wing, 1998). In fact even advocates who claim that the conditions are distinct such as Klin et al. (1995) concede that differences between Asperger syndrome and high-functioning autism (in for example verbal and performance IQs) may not be the manifestation of two different conditions. They acknowledge that Asperger syndrome and high-functioning autism may be one diagnostic condition that is simply expressed differently, due in part to neuropsychological endowment, as with the commonalities between low and high-functioning autism.

It has recently been stated that the reasonable approach to this issue would be to accept that "although there may be sub-groups that are specific and separate at some level of discourse, at present these have not been identified" (Wing, 2000; p424). Due to this ongoing debate and the uncertainties of the diagnostic tools used to identify Asperger syndrome (Mayes, Calhoun & Crites, 2001) most researchers currently conceptualise Asperger syndrome as akin to high-functioning autism (e.g. Baron-Cohen, Wheelwright, Spong, Scahill & Lawson, 2001). As a result the current thesis views a diagnosis of Asperger syndrome as being a variant on the autistic spectrum that is similar in nature to high-functioning autism. Consequently this thesis will refer to high-functioning autism as synonymous with Asperger syndrome. The value of studying high-functioning individuals in whom autism is not confounded with mental retardation has also been argued convincingly (see Prior, 1979) and this approach has therefore been adopted in the studies reported in this thesis.

According to recent reviews autistic spectrum disorders affect approximately six in every 1000 children under eight years (MRC, 2001). Autistic spectrum disorders are four times more prevalent in boys than girls (Rutter, 1985) and, although females are less likely to develop them, when they do they are generally more severely impaired (Lord & Schopler, 1987; Wing, 1981). Current research states that autistic spectrum disorders have a variety of causes that appear to affect sites in the brain concerned with social and communicative development (MRC, 2001). Indeed, although an exact location has not been pinpointed many studies have reported that the brains of

individuals with autism do manifest abnormalities (Trevvarthen, Aitken, Papoudi & Robarts, 1996). In many cases of autistic spectrum disorders there is strong evidence to suggest that interacting genetic influences are at play (Bailey, Palferman, Heavey, & Le Couteur, 1998; Bailey, Phillips & Rutter, 1996; Bolton, MacDonald, Pickles & Rios, 1994). The genetic basis of autism is believed by researchers to be highly complex, probably involving several genes in combination (Howlin, 1998; Tsai, 1999). Epidemiological studies have demonstrated that the probability of both twins having autism is higher if they are monozygotic (Bailey et al., 1995; Folstein & Rutter, 1977a). Likewise, the rate of autism in siblings is between 3 and 7%, higher than the rate shown in the rest of the population (Jorde et al., 1991; Piven et al., 1990). The evidence of a genetic basis is further reflected in the term 'broader phenotype' that has been introduced to convey the observation that, within families of children with autism, other relatives are more likely to exhibit symptoms generally associated with the condition (Baron-Cohen, Tager-Flusberg & Cohen, 2000; Folstein & Rutter, 1977a; 1977b). Weight is also added to the genetic argument by the evidence that autism often co-occurs with other conditions which are genetically determined such as Down syndrome, fragile X, phenylketonuria and tuberous sclerosis (Blomquist et al., 1985; Gillberg & Forsell, 1984; Hunt & Dennis, 1987). For the purpose of this thesis, it was important that only children with a clinical diagnosis of autism and no co-morbidity with other conditions were included.

### **1.7.2. Symptoms**

Autistic spectrum disorders are defined by early emerging, qualitative impairments in communication, social interaction and imagination and the presence of a narrow and repetitive range of actions. As will be shown in Chapter 2, these symptoms are often presented as impairments in intuitive psychology. A brief description of the symptoms will now be presented. However, since autism is a spectrum disorder it is unlikely that a child with this condition would exhibit all of these behaviours.

With regard to non-verbal communication, typically developing infants, prior to the onset of language, are capable of communicating with others through the use of gaze, facial expressions and sounds (see Trevvarthen et al., 1996). However, in children on the autistic spectrum these means of communicating are, if not absent, often limited (Mundy & Sigman, 1989). For example, they have problems with most types of imitation, from the basic imitation of smiles, present in typically developing children as

young as two months, to more advanced imitation such as games like pat-a-cake and simple gestures, usually present by 12 months (Sigman & Ungerer, 1984; Volkmar, 1985). Other forms of early communicative behaviour such as eye-to-eye gaze is also absent or at least atypical (Siegel, 1996a).

Language development in children on the autistic spectrum is slow and around half of the population fail to develop functional speech, with many having little (or no) understanding of spoken language (Lord & Rutter, 1994). Atypical use of language is noticeable early, and infants with autism exhibit a limited range and lower complexity of babbling compared to typically developing children and do not use these sounds as a means to communicate with others (Howlin, 1998). Children on the autistic spectrum do not attempt to compensate for their lack of speech by communicating in other ways. For example, the gestures, facial expressions, head nods, smiles and 'uh-huhs' used to support communication in typically developing children are usually absent (Ricks & Wing, 1975).

Not all individuals diagnosed with an autistic spectrum disorder have severe language impairments and some, usually those diagnosed as high-functioning, can use language effectively. However these children do not use language in its conventional form and tend to exhibit atypical patterns of speech. For example, they often use unusual metaphors and may speak in a formalised manner often referring to themselves as 'you' (i.e. 'you want a biscuit' meaning 'I want a biscuit'), they may also exhibit sparse verbal expressions and overall, show a lack of spontaneity when speaking (Prior, 1977). A prominent characteristic in the language used by children with autism is 'echolalia', speech that consists of the repetition of something heard either at the time or earlier i.e. delayed echolalia (Siegal, 1996a).

Children with autistic spectrum disorders lack many fundamental social skills that are present in typically developing children at a young age. For example, they display a diminished range of emotional expressions and cannot identify emotional states in others (i.e. no recognition of affect). In addition, the ability to decipher emotions and discriminate between them is not present in infants with autism and even older children on the autistic spectrum find this difficult (Hobson, 1983; 1986; Smalley & Asarnow, 1990). Furthermore, children with autism exhibit an attachment behaviour

that has been described as 'actively avoidant'. They do not cling to a primary caregiver in new and strange situations (Siegal, 1996a) and have been found to be just as content in the company of a stranger as they are with a primary caregiver (Volkmar, 1985).

Children on the autistic spectrum tend to keep their distance from other people and even prefer to sit with a parent side by side when playing (Siegal, 1996a). They are less responsive to social cues conveyed by eye contact and smiles and tend to cut themselves off from emotional and communicative transactions with those around them (Hobson, 1983; 1987; Tinbergen & Tinbergen, 1983). These characteristics lead to a lack of co-operative play with peers, an impaired ability to develop friendships, and an inability to understand other people's feelings. Indeed it is not surprising that children on the autistic spectrum are often described as being in a 'world of their own'. When individuals with autism do engage in social interactions, the interactions often occur less frequently and will often be very rigid even when the situation changes (Siegal, 1996a).

In contrast to their peers, children with autistic spectrum disorders lack spontaneous and imaginative play (Wulff, 1985). When they do play with toys, it is noticeable that no thoughts and feelings are introduced to the situation and, in more cases than not, play is often limited to 'non-functional' behaviour such as lining up objects i.e. not using the objects for their intended purpose (Black, Freeman & Montgomery, 1975). Many children with autism show an unusual preference for one particular object that may be stimulating for them and they do not appear to get easily bored with it. In addition, they are often pre-occupied with one part of an object, being unable or unwilling to see the object as a whole (Siegal, 1996a).

The repetitive behaviours seen in children with autism may take the form of repeated body movements, such as hand flapping, twisting, spinning, balancing and rocking. In addition, they often display repetition in many aspects of their life such as following the same route, the same order of dressing or the same daily schedule. Many show an obsessive interest in a single item, idea, activity or person and if changes occur in these routines, the preoccupied child can become very distressed.



Many theorists have attempted to link the behaviours associated with a diagnosis of autism to cognitive theories of development. In the remaining section of this chapter three cognitive accounts of autism will be presented. At present, these theories can be divided into those that posit a primary social impairment i.e. the theory of mind hypothesis, and those that attribute a primary non-social impairment i.e. executive functioning and central coherence hypotheses (see Zelazo, Burack, Boseovski, Jacques & Frye, 2001).

### **1.8. Cognitive Accounts of Autism**

The 'social' deficit account, namely the theory of mind hypothesis, is intrinsically domain-specific and argues that a deficit in 'theory of mind' makes it hard for children on the autistic spectrum to engage with psychological phenomena. Implicit in this account is that other areas of cognition will be relatively unaffected (Baron-Cohen, 1995; Leslie & Roth, 1993). In contrast, the executive functioning and central coherence accounts of autism can be considered as domain-general theories of autism. Both claim overarching 'non-social' general cognitive processes are responsible for the behavioural profile of children on the autistic spectrum, which will inevitably affect learning across all domains of knowledge (Frith, Happe & Siddons, 1994; Ozonoff, Rogers & Pennington, 1991).

The theory of mind hypothesis concerns the domain of intuitive psychology (to be discussed in more detail in Chapter 2) and refers to the ability to attribute mental states (e.g. beliefs, desires) in order to predict and explain behaviours. Research suggests that typical children develop a theory of mind in a basic form in the second year of life and fully by the age of four years (Wimmer & Perner, 1983). However, this core cognitive mechanism is impaired (or even absent) in individuals with autism (for a review see Baron-Cohen et al., 2000). As will be discussed in Chapter 2, children on the autistic spectrum cannot form a mental image of what goes on in the minds of others. Although a minority of individuals with autism have been found to pass simple theory of mind tasks they do, more often than not, fail more complex tasks (Baron-Cohen, 1989a). This deficit is arguably present in all individuals with autism. Moreover, as autism appears to be a neurological disorder with a genetic basis many people have suggested that theory of mind understanding develops from an innate and dedicated neurological site (Zelazo et al., 2001). However, the theory of mind hypothesis has difficulty in



explaining some non-social aspects of autism such as the failure to generalise skills and most notably, the presence of repetitive and stereotypical actions (Zelazo et al., 2001). These behaviours have been described by more domain-general accounts of cognitive development that link the development of general cognitive skills with the acquisition of specific knowledge. The executive functioning hypothesis is one such example.

Executive functioning is a term given to a collection of domain-general skills that are necessary to control behaviour. These include abilities such as planning future action, impulse control, inhibition of pre-potent but irrelevant responses and flexibility of thought or action (Ozonoff et al., 1991). In short, executive functions are needed to maintain a mentally specified goal and bring it to fruition against other alternatives (Perner & Lang, 2000). Findings from empirical studies have shown that many children with autism, even high-functioning individuals, perform badly on tasks of executive functioning such as the Tower of Hanoi and the Winconsin Card Sorting Task (Hughes, Russell & Robbins, 1994; Rumsey & Hamburger, 1988; 1990). This deficit in self control of action is said to account for the repetitive and rigid behaviours witnessed in many individuals with autism as well as their problems with participating in pretend play (Jarrold, Butler, Cottington & Jimenez, 2000).

The necessity for executive functioning abilities in meta-representational tasks has been argued for extensively (see Perner, Stummer & Lang, 1999) and it has been suggested that the inability to inhibit a pre-potent response to salient external stimuli (due to executive dysfunction) can account for failure on tasks of theory of mind (Perner & Lang, 2000; Robinson & Mitchell, 1995; Russell, Saltmarsh & Hill, 1999). In fact, performance in executive functioning has been shown to correlate positively with performance on several theory of mind tasks (Hughes, 1996; Ozonoff & Strayer, 1997; Russell, Mautherner, Sharpe & Tidswell, 1991).

There are problems with the executive functioning account of autism and it has recently been suggested that executive functioning deficits are common but not a necessary feature of autism (MRC, 2001). In addition, there is evidence of executive functioning difficulties not accompanied by social abnormalities in a wide array of developmental disorders including Attention Deficit Hyperactivity Disorder and Williams syndrome. Likewise, individuals with Tourette's syndrome experience executive functioning

problems without any accompanying impairment in intuitive psychology (Baron-Cohen & Swettenham, 1997). These findings appear to argue against a causal link from executive functioning to theory of mind skills.

An alternative domain-general explanation concerns 'central coherence'. Central coherence is described as an ability that functions to draw together diverse information in order to construct higher level meaning in context. For example, central coherence capacities allow us to recognise, with ease, the contextually appropriate sense of the many ambiguous words in everyday speech i.e. son/sun (Happe, 1994a). The drive for coherence is an organising principle in normal human cognition and appears 'weak' in individuals with autism (Frith & Happe, 1994).

Weak central coherence results in a particular cognitive style that has been assigned to all individuals on the autistic spectrum (Frith, Happe & Siddons, 1994) and, as a result, it is argued that they are free from contextual constraints. This feature (or lack of it) may help to explain why children with autism show an advantage on tasks that involve preferential processing of parts over wholes such as the block design sub-test of the Weschler Intelligence Scale for Children (Shah & Frith, 1983). However, weak central coherence would also manifest itself in poor performance on tasks that involve interpretation of individual stimuli in terms of overall context and meaning, just the type of ability that is needed in many social situations. As a result, deficits in theory of mind are seen by some as one consequence of weak central coherence, i.e. inability to derive high-level meaning from social situations (Frith, 1989). In support of this argument a negative correlation has been found between theory of mind abilities and performance on an embedded figures task which taps abilities of central coherence (Jarrold et al., 2000).

It must be noted that a causal link between autism and central coherence has been dismissed by the finding that weak central coherence is evident in individuals who pass theory of mind tasks (Happe, 1994a). In addition, there is evidence that children with general developmental delay (Yirmiya, Erel, Shaked & Solomonica-Levi, 1998) and children who are deaf from non-signing families (Petersen & Siegal, 1997; 1998) also fail tasks of theory of mind and yet have no anomalies in central coherence (see Happe, 2001).

It has been suggested that one single cognitive abnormality is unlikely to give a full account of autism. Domain-general accounts (i.e. executive functioning and central coherence) face the challenge of accounting for some very specific social impairments and it is hard to see how they could account for the accumulating pattern of deficits on their own (Happé, 2001). Furthermore, their links to theory of mind deficits make it hard to disentangle the original cause. Likewise, it has also been argued that the domain-specific account of autism (i.e. theory of mind) cannot successfully explain the presence of non-social features such as repetitive behaviours (Happé, 2001). In order to disentangle these issues further attempts need to be made to incorporate findings and paradigms from the domain-specific theories discussed previously. For example, if the difficulty in understanding mental states in children with autism stems from a domain-specific cognitive architecture, this implies that other domains of thought will not be impaired. This hypothesis would not be supported by domain-general accounts such as executive functioning or central coherence.

### **1.9. Outline of this Thesis**

This chapter has shown that many prevalent theoretical accounts of cognitive development take a domain-specific perspective. The position of developmental psychopathology has also been highlighted. This approach attempts to integrate research findings on typical and atypical development and, in-keeping with this paradigm, the symptoms of autism were described. Autism has been associated with domain-general and domain-specific theoretical accounts of development. The latter predicts an uneven cognitive skills profile and for this reason, focus must be turned to not only the weaknesses but also the strengths of children on the autistic spectrum. If asynchronous patterns of development were found then this would provide support for the domain-specific nature of cognition.

Despite many attempts to characterise the mechanisms that are involved in the development of children's knowledge, present day developmentalists are still often unable to proceed with confidence. Flavell (1984; p189) asserts that this is because "good theorising about mechanisms is very, very hard to do". As a result, domain-specific accounts of cognition often emphasise the importance of investigating the content of children's knowledge, specifically in relation to psychological, physical and biological phenomena. Wellman and Inagaki (1997b; p1) very eloquently describe this

knowledge as “both the products and the containers of childhood cognition and development”.

This domain-specific focus on the content of children’s knowledge has highlighted that children on the autistic spectrum demonstrate an uneven cognitive profile whereby impairments in the domain of psychology are present alongside an apparent ability to reason about physical phenomena (see Baron-Cohen, 2000a). However, the evidence is far stronger for claims made with regard to weaknesses in psychological understanding than it is for relative strengths in physical understanding. As a result there is a real need to examine whether children on the autistic spectrum can indeed reason about physical phenomena and if they can, attempts must be made to assess this ability in relation the developmental pattern found in typically developing children.

In an attempt to shed light on this matter, the following introductory chapters, Chapters 2 and 3, will focus on the question of what actually develops in relation to children’s understanding of psychological and physical phenomena. They will review the research with respect to both typically developing children and children on the autistic spectrum from infancy to upper primary school age. On the basis of this literature review the two empirical studies reported thereafter (Chapters 4 and 5) will explore the discontinuity in the development of psychology and physics in children on the autistic spectrum. Following this, the final study in this thesis (Chapter 6) will examine in more detail the nature of physical understanding in both children on the autistic spectrum and typically developing children by looking at the predictions and explanations they offer in order to reason about four physical concepts. A general discussion of the findings of all three studies will be presented in Chapter 7.

## CHAPTER 2

# INTUITIVE PSYCHOLOGY: UNDERSTANDING IN TYPICALLY DEVELOPING CHILDREN AND CHILDREN ON THE AUTISTIC SPECTRUM

### 2.1. Aims of this Chapter

Chapter 1 outlined key characteristics relating to domain-specific theoretical accounts of cognitive development. Central to these accounts is the claim that children's understanding develops independently across knowledge domains. Most researchers in this field have identified the existence of domain-specific knowledge pertaining to psychological phenomena (e.g. Carey, 1985; Wellman & Gelman, 1992; Wellman, Hickling & Schultz, 1997; 2000) and as a result, many consider a domain of psychology as being a fundamental part of cognition (Karmiloff-Smith, 1992; Leslie, 1994). This chapter will argue that the initial acquisition of psychological knowledge is a result of innate mechanisms. As will be shown, the main thrust of this argument comes from experimental work with young infants. Findings identifying a number of 'building blocks' pertaining to the domain of psychology will be presented. It will be argued that these support the subsequent development of core psychological concepts. This chapter will also consider the understanding of intuitive psychology in children on the autistic spectrum. Attempts will be made to examine the research findings used to demonstrate the lack of psychological understanding evident in this group.

### 2.2. Introduction

Research on psychological concepts is far from a new area of investigation. As early as 1932 Piaget looked at children's understanding of belief, intention and lies. As a result of this work, he concluded that children under the age of seven do not distinguish between mental and physical realms, preferring to rely exclusively on the physical world as a means of construing psychological phenomena (Piaget, 1932). Over the years psychological understanding in young children has become a 'hot' area of research. Although this new wave of interest has undermined much of Piaget's work, Karmiloff-Smith (1992; p117) points out that "in every case, most of the fundamental issues



involved were first raised by Piaget, even though his theoretical answers are, for many, no longer viable”.

Today, most of the research in the domain of psychology is concerned with three assumptions regarding the mind (Lee & Homer, 1999). The first assumption revolves around the notion of representation, i.e. events occur, the mind can represent these and different minds can often hold different representations. The second assumption is concerned with knowing that the mind has other core functions that allow us to explain and make predictions about other people’s actions. These concepts fall under the domain of ‘psychology’ and include believing, perceiving, intending and desiring. The final assumption concerns the causal nature of the mind. This allows us to know that there are causal relations between mental activities such as seeing leads to knowing, and between mental activities and behaviours, for example, that false beliefs lead to misguided actions. The explanatory system encapsulating these three assumptions has been referred to as naïve psychology (Wellman & Gelman, 1992), theory of mind (Dennett, 1971; Clark, 1987), folk psychology (Stitch & Nichols, 1995), common-sense psychology (Forguson & Gopnik, 1988), mind-reading (Baron-Cohen, 1995) and intuitive psychology (Humphrey, 1986). Within the literature, the term ‘theory of mind’ is probably the most commonly used description. However, as we will see, this term is now intricately linked to children’s understanding of belief. Belief is only one aspect of children’s psychological knowledge and as such, this thesis will employ the term ‘intuitive psychology’ to represent the broader basis of an understanding of the mind.

Contrary to Piaget’s views, researchers now accept that children as young as three years can reason comprehensively about psychological phenomena (among others, Carey, 1985; Estes, Wellman & Wooley, 1990; Wellman & Lagattuta, 2000). This work has led Karmiloff-Smith (1992) to describe young children as ‘spontaneous psychologists’ who are driven to understand basic psychological concepts very early in life. As mentioned in Chapter 1, Karmiloff-Smith (1992) argues that domains function in order to constrain interaction with one’s environment. In the case of psychology, she believes that constraints guide the infant’s recognition of others, allowing them to identify common behaviours and engage socially. Without an understanding of intuitive psychology, it would be impossible to predict others behaviour, understand their beliefs, intentions and desires, interpret statements, gestures or actions, or

interpret facial expressions (Olson, Astington & Harris, 1988; Stich, 1983). As will be shown in the following section, a wealth of research supports the premise that an understanding of the mind is evident from a very early age and possibly arises as a result of innate underpinnings. According to Fodor (1987; p132) it is not entirely surprising that this is the case, he asserts that "if I had been faced with this problem in designing *Homo sapiens*. I would have made common-sense psychology innate; that way nobody would have to spend time learning it!"

### **2.3. Basic Building Blocks of Intuitive Psychology**

Even in the first few days of life human infants specifically orientate themselves towards social stimuli. This finding is clearly demonstrated in an ingenious experiment by Johnston and Morton (1991) who presented newly born infants (some no more than nine-minutes-old) with four boards; three constituting different configurations of the face and one with a chequered pattern. Results showed that infants preferentially attend to stimuli displaying the normal configuration of the face. It was concluded that infants possess innately specified structural information about human faces that leads to their preferential attention towards them (Johnston & Morton, 1991). At three months infants can differentiate between a smiling and non-smiling face (LaBarbera, Izard, Vietze & Parisi, 1976; Young-Browne, Rosenfeld & Horowitz, 1977). By seven months they can discriminate between faces of different sexes as well as between different orientations of the same face (Fagan, 1972; 1976). Furthermore, by 24 months, infants are able to identify from a choice of three expressions the one that depicts basic emotions such as 'happy' and 'sad' (Izard, 1971). Not only do infants use face recognition to identify other people but they also use speech. At birth infants would rather listen to human speech than other auditory input (Karmiloff-Smith, 1992) and by nine months, infants can recognise that a happy smiling face will accompany a happy tone of voice (Nelson, 1987; Walker-Andrews, 1997).

As well as attending to stimuli of a psychological nature, young infants can successfully engage in social interaction. One of the first manifestations of social interaction to be witnessed in the young infant is imitation. Basic imitation has been demonstrated in new-borns as young as 42-minutes-old (Meltzoff & Moore, 1983; 1989) and, 12 days from birth infants can imitate tongue protrusion, mouth opening and lip protrusion (Meltzoff & Moore, 1977). Imitation serves to help the infant identify, understand and

recognise people (Meltzoff & Moore, 1977). As such, it has been suggested that imitation may provide the foundation for subsequent understanding regarding the mind (Meltzoff & Moore, 2000; Tager-Flusberg, 1989). The initial preference for human stimuli and the basic need to engage socially appear to facilitate the development of joint communication between an infant and adult. Joint communicative behaviours come in many guises, including gaze following, social referencing, non-verbal and basic verbal communication (Wellman & Lagattuta, 2000). Infants aged eight-to-fourteen months appear to co-ordinate these behaviours and in general, employ them in order to share a social experience (Baldwin & Moses, 1994; Carpenter, Nagell & Tomasello, 1998; Trevarthen & Hubley, 1978).

As detailed in Chapter 1, Leslie (1987; 1994) attributes an understanding of psychological phenomena largely to the presence of ToMM. He suggests that ToMM *system 1* arrives in development around the age of six-to-eight months and is concerned with Agents and their goal-directed behaviour. Leslie suggests that the onset of *system 1* can be identified by the infant's use of eye gaze. In support, work has shown that from the age of six months, infants can follow someone else's gaze direction (Scaife & Bruner, 1975). Moreover, infants aged ten-to-fourteen months can initiate gaze alteration between a caregiver and an object they wish to obtain (Butterworth, 1991). Leslie (1994) also suggests that ToMM *system 1* is employed by infants in situations where Agents 'come together and interact'. A prime example of this is pointing behaviour that emerges in development between ten and thirteen months (Butterworth, 1991). In its early stage pointing is characterised as 'proto-imperative' and usually involves the infant trying to obtain an object. This behaviour assumes an understanding of intentionality since it requires that the child attributes an internal state towards a specific object e.g. 'I want that toy' (Karmiloff-Smith, 1992). At the age of two years, the child's pointing behaviour is more sophisticated and 'proto-declarative' actions become noticeable. This type of pointing behaviour indicates an understanding that people can be perceptually directed towards the stimuli in question e.g. 'look at that toy' (Masur, 1983). According to Leslie (1994), this rapidly accumulating understanding allows infants to further develop their intuitive understanding of psychology.

As well as being able to attribute their own intentions towards an object, infants as young as ten months can successfully seek information from a parent and interpret it in

terms of the parent's inner emotional feelings. For example, they avoid toys to which their mother has previously showed disgust (Hornick, Risenhoover & Gunner, 1987). A further striking example of social referencing skills in infants is that when placed across a visual cliff, an infant will cross if a caregiver smiles but will not move if the caregiver appears fearful (Klinnert, Campos, Sorce, Emde & Svejda, 1992; Sorce, Emde, Campos & Klinnert, 1985). Additionally, infants aged 18 months appreciate not only that they can be influenced by others, but that others can be also orientated towards objects that can be experienced as pleasing, scary, desired or undesired (Walden & Ogan, 1988). These abilities allow young infants to conceptualise the self and others in very different terms and they start to conceive of people as intentional beings (Wellman & Lagattuta, 2000). A parallel development in infancy involves the ability to differentiate psychological and physical phenomena. This is pertinent if separate domains of understanding are to be accepted as components of cognition. Some examples of this work will now be presented.

Infants can distinguish between human behaviour and behaviour exhibited by physical objects (Leslie, 1984; Premack, 1990). For example, as early as four weeks infants demonstrate short spans of attention to their mothers while attending fixedly for longer at an object (Brazelton, Kolowski & Main, 1974). In addition, they can discriminate between animate and inanimate movement, overall preferring to attend to the former (Bertenthal, Proffitt & Kramer, 1987; Bertenthal, Proffitt, Spetner & Thomas, 1985). The ability to view these two types of stimuli as different has important implications for the future development of intuitive psychology concepts. It allows young infants to understand people as 'subjects' that are capable of self-initiated action and not as Piaget (1952) argued, 'objects among other objects' (Karmiloff-Smith, 1992)

By the age of two years, infants can clearly distinguish between psychological and physical worlds (Leslie, 1987; McCune-Nicolich, 1981). For example, when asked about a boy who thought about a cookie, and a boy that had a cookie, young children correctly judged that it is the real cookie that can be seen by oneself and others, touched and manipulated (Wellman & Estes, 1986). An ability to distinguish between the mental and the physical world is needed in order to engage in pretend play. Pretend play requires children to understand their relationship with a primary representation i.e. the actual objects being played with, and a secondary representation i.e. the content of the



pretence (see Karmiloff-Smith, 1992). According to Leslie (1994) the onset of pretend play and the ability to recognise pretend play in others results from the activation of ToMM *system 2* at approximately 18-to-24 months of age. At this age infants also start to use mental state terms such as 'think', 'remember' and 'know' (Bretherton & Beeghly, 1982; Limber, 1973). Young children use these terms to explain the difference between the mental and physical worlds; for example, they explain that persons but not rocks or dolls can see, think, remember and be happy (Gelman, Spelke & Meck, 1983; Johnson & Wellman, 1982).

Many of the basic psychological concepts that operate in order to allow young infants to engage in social interaction emerge early and appear spontaneously in typical development. This level of understanding has been described as implicit knowledge (see Chapter 1) and because it has been identified, in some cases, among infants no more than a few days old it has been argued that, "humans are provided with an innate mechanism for social learning" (Meltzoff & Gopnik, 1993; p352). Infants appear to have a basic drive to engage socially, and from an early age appreciate the distinction between psychological and physical phenomena. It has been argued that these foundational skills are 'theory-like' and allow the young infant to gain relevant information from the environment (Gopnik & Meltzoff, 1997). The resulting understanding is then used to shape future understanding of core psychological concepts. It is to these concepts that this chapter will now turn.

#### **2.4. Key Intuitive Psychology Concepts**

Many intuitive psychology concepts that develop during the pre-school years can be neatly described in relation to Wellman's (1990) 'belief – desire' dichotomy. Put simply, this refers to the understanding that human behaviour is led by the joint existence of beliefs and desires that in turn affect behaviour. The concept 'desire' involves motivational states such as wishes, wants and needs. The concept 'belief' encompasses mental attitudes towards the world such as perceiving and knowing and is also reflected in the ability to deceive. At present, studies investigating belief are over represented in the literature. Only recently has attention turned towards other concepts within the domain, such as desire (Wellman, Phillips & Rodriguez, 2000).



It has been argued that the concepts within the domain of psychology are independent yet can be defined in relation to one another. For example, an understanding of belief may be supported by other intuitive psychological concepts such as desire and perception (Wellman, Phillips & Rodriguez, 2000). In the next section, children's understanding of intuitive psychology will be described in approximately the order that the concepts emerge in typical development. An understanding of the concepts 'perception' and 'knowledge' will therefore be outlined before 'desire' which will be followed by 'belief' (see Wellman, 1990; Wellman, Phillips & Rodriguez, 2000).

#### **2.4.1. Perception and Knowing**

An understanding of perception is a central feature of intuitive psychology because in many situations, perception anchors a person's mind within the world and provides information regarding objects that a person may want or desire (Wellman & Lagattuta, 2000). Likewise, understanding the reasons for knowing and not knowing is crucial to a developing domain of psychology. It has been claimed that an early understanding of perception and knowledge may provide a model for a later understanding of belief (Gopnik & Wellman, 1994; Perner, 1992). Moreover, as will be shown, the concepts of perception and knowledge are intrinsically linked.

On the basis of Piaget's work, it was accepted for many years that children under the age of six were 'egocentric' when asked to take the perspective of others and thus would wrongly assume that information held by themselves was available to other people. However, over the years, studies have highlighted that this premise underestimates the abilities of children. For example, from as early as 12 months of age linguistic terms intrinsically linked to perception such as 'look' and 'see' appear in infants' speech (Bretherton & Beeghley, 1982). By the age of two the majority of children can understand that differing perspectives may lead to differential knowledge acquisition. For example, when two objects were placed on a table divided by a screen, they correctly identified the object on their side of the screen, as well as the object seen by the experimenter on the other (Flavell, 1978), an ability described by Wellman and Lagattuta (2000) as Level-1 perspective taking. Young children not only appreciate that one can have a different perspective of a situation but they also understand that 'seeing leads to knowing' (Flavell, 1977a, 1977b; Pratt & Bryant, 1990). For example, three-year-old children acknowledge that one must look inside a box and not just be physically

near it in order to know what is inside (Pillow, 1989). Moreover, by the age of four, children appreciate that knowledge is interpretative and/or constructive in nature (Wellman, 1990).

A more developmentally advanced understanding of perception and knowledge can be demonstrated via children's performance on appearance-reality tasks. The appearance-reality distinction tests children's ability to engage in perceptual perspective taking. Success comprises knowing that an object's appearance may not reflect its status in reality and the task involves presenting children with an object such as a sponge that looks like a rock (Flavell, Green & Flavell, 1986). Children are asked an appearance question: 'what does it look like?' and a reality question: 'what is it really?' Using this paradigm studies have reported consistent failure in three-year-old children who claim that the object's appearance and reality are indeed the same, even with training the pass rate did not improve with age (Flavell et al., 1986). It is not until the age of four that children can correctly grasp the dual representation of the object in question (Flavell, Flavell & Green, 1983). However, it has recently been shown that given a different set of test questions children younger than four years can successfully pass the appearance-reality task. Using the rock-sponge exemplar, Sapp, Lee and Muir (1997) reduced the linguistic demands of the task and asked children to respond via non-verbal behaviours. As a result, when instructed to choose an object that would wipe up spilled water, children aged three correctly chose on the basis of the object's real property i.e. the sponge. In addition, when asked to choose an item that looked like a rock for a picture taking session, the children chose the item according to appearance i.e. the rock, thus clearly appreciating the distinction between appearance and reality.

#### **2.4.2. Desire**

In order to reason about another's behaviour an understanding of motivational states such as desires, wishes, wants and needs is essential (Wellman & Lagattuta, 2000). Desire is a central concept within the domain of psychology and appears early in development (Bartsch & Wellman, 1995; Wellman & Wooley, 1990). In an ingenious study, Repacholi and Gopnik (1997) showed that infants aged 18 months understand that people have desires and that these desires can differ and may even conflict. They presented infants with two bowls of food namely Goldfish crackers and raw broccoli. The infants were clearly shown to prefer the crackers. Following this, the experimenter

tasted each type of food and differentiated them by showing a delighted face and stating 'Yum' to one and making a disgusted face and the comment 'Yuck' to the other. The bowls of food were then placed in front of the infants who were asked to 'feed' the experimenter some food. When the experimenter indicated that she loved the crackers and hated the broccoli all the infants diligently gave her the crackers however, when the opposite was true i.e. loving the broccoli but hating the crackers, the infants were presented with a situation where the experimenter's desire conflicted with their own. Results showed that infants age 14 months always presented the crackers, an action in accordance with what they wanted. It was not until 18 months that infants correctly presented the broccoli, even although they themselves preferred the crackers.

Although it has been claimed that research investigating the concept of desire is currently lacking (Wellman, Phillips & Rodriguez, 2000) studies have shown that from the age of two children use the linguistic term 'want' in order to talk about their desires (Bartsch & Wellman, 1995). Additionally, at two and a half years children know that we try to get what we want and understand that happiness will occur if we get it but disappointment will ensue if we do not. Further, they have established that different people have different desires and more significantly, they can talk about desires without any accompanying action (Wellman & Lagattuta, 2000). These results suggest that from the age of two years children can understand the concept of desire as a genuine mental state (Astington & Gopnik, 1991; Wellman & Wooley, 1990).

### **2.4.3. Belief**

A belief is a mental representation of the world and many mental attitudes including perceptions, thoughts and expectations are encompassed in this concept. Having an understanding of belief is considered to be a landmark development in children's understanding (Wellman & Lagattuta, 2000). However, the concept of belief is only one of the many milestones that children must appreciate in order to have a fully-fledged domain of psychology. Despite the vast amount of research dedicated to this concept, an appreciation of belief is only important because it provides evidence about whether a child has a basic understanding of the intentional state of the mind (Lee & Homer, 1999). This section will present a brief overview of the main studies investigating the concept of belief in young children. The vast majority of this research has focussed on children's understanding in relation to 'false beliefs'. In the following section this work



will be presented alongside findings from one other paradigm (i.e. deception) Attention will be given to claims regarding the age at which an understanding of belief is evident and methodological issues pertinent to work on this concept will be discussed.

In order to be credited with an understanding of the mind many researchers argue that a child must be able to understand that people can be mistaken in their beliefs, i.e. that people can have false beliefs. Developed by Wimmer and Perner (1983) and modified most notably by Baron-Cohen, Leslie and Frith (1985) false belief tasks have been employed to provide evidence for the presence of a theory of mind. There are two basic types of false belief tasks. The first is known as the 'unexpected transfer task'. This task involves giving participants information about a character's belief then asking them to predict the character's subsequent action. For example, in the now classic 'Sally/Anne' experiment, participants are asked to observe a scene acted out with toy dolls named Sally and Anne. The first action involves Anne placing a marble under a basket and leaving the room. When out of the room Sally moves the marble from under the basket and places it under a box. Participants are then shown Anne re-entering the room. To determine whether participants have an understanding of the mind, children are asked the key question 'where will Anne look for the marble?' If participants answer correctly, i.e. the basket, then they have grasped the notion of false beliefs. On the contrary, if they answer that Anne will look in the box then they do not understand that beliefs can be mistaken. Results from numerous studies (including Peterson & Siegal, 1998; Surian & Leslie, 1999) have shown that three-year-old children perform poorly on this task. In contrast, children aged four correctly predict that Anne will look in the basket, an action that is consistent with her (albeit wrong) belief.

The second type of false belief paradigm that is widely administered is described as the 'unexpected contents task'. Devised by Hogrefe, Wimmer & Perner (1986) and replicated by many others (e.g. Gopnik & Astington, 1988; Perner, Leekham & Wimmer, 1987) this task requires participants to state what they believe is in a familiar container such as a 'Smarties tube'. However, when the container is actually opened it contains something unexpected such as pencils. Following this revelation, participants are asked to predict what someone else viewing the container for the first time would think is inside the tube. Children aged four correctly predict that the new person will think that the tube contains 'Smarties' but most three-year-old children predict that

she/he will think the tube contains pencils. This answer demonstrates that three-year-olds do not grasp that the representation held in their mind can be different from that held in another's and cannot appreciate the often false nature of beliefs.

Developmental findings from false belief tasks are very consistent and indicate that children under four years cannot represent false beliefs and therefore do not have a full understanding of the mind (Perner, 1992; Perner et al., 1987). However, a growing body of researchers claim that standard false belief tasks have methodological shortcomings and do not accurately tap into the young child's repertoire of intuitive psychology (e.g. Chandler, Fritz & Hala, 1989; Siegal, 1996b). In order to investigate this possibility Siegal and Beattie (1991) employed more sensitive research methods in an unexpected transfer task. They showed that when asked 'where will Anne look *first* when she returns?' children aged two to three years correctly reported that she would look in the basket. The authors suggest that the reported failure of this age group on standard false belief tasks results from 'conversational rules' implicated in the testing situation. These factors are also involved in the unexpected contents task. For example, if asked 'before I opened the box, what did you think was in it?' instead of 'when I opened the box, what did you think was in it?' the performance of children younger than four years significantly improves (Lewis & Osborne, 1990). Similar results have been found by making salient the prior mental state i.e. that the child first thinks it is Smarties in the box (Mitchell & La Cohee, 1991; Zaitchick, 1991). These studies, and many more besides, have highlighted that modifications such as minor wording changes (Freeman, Lewis & Docherty, 1991; Moses, 1993; Surian & Leslie, 1999), introducing memory aids (German & Leslie, 2000) or making the change of location less salient (Carlson, Moses & Hix, 1998) yield more positive findings with respect to the ability of children under the age of four to understand the nature of false beliefs.

A large number of studies have focused on false belief tasks but the concept of deception can also be used to tap children's understanding of belief. Deception involves trying to make someone else believe that something is true when it is in fact false and as such involves an understanding of belief. Without knowing that beliefs can be manipulated, can be true or false, and people will behave in accordance with what they believe, the ability to deceive would be impossible. Studies have shown that young children are capable of basic teasing and deception (Hala & Carpendale, 1997).



However, as Baron-Cohen (2000a) points out, children's early attempts at deception are usually clumsy and unsuccessful. For instance, many adults have experienced the child who claimed not to have eaten the chocolate but had the evidence all over his face!

It has been shown that if an action is in the child's own self-interests, or if their self-interests are directly threatened, then children aged two years can actively engage in deceptive talk/action. Chandler et al. (1989) investigated the concept of deception by asking two, three and four-year-old children to help a doll named Tony hide 'treasure' from an adult. This scenario involved the doll's footprints leading to the treasure being evident and the children were instructed to 'think of something' to prevent the treasure being found. Subsequently the children were asked to explain the deceptive strategy they employed. Results showed that in every age group children employed four main deceptive strategies: 1) withholding evidence; 2) destroying evidence such as wiping the trail; 3) producing false information without destroying evidence; and 4) producing false information and destroying evidence. Furthermore, it was found that the majority of children in each age group could justify their deceptive acts. These results provide convincing evidence that given the correct circumstances, two-year-old children can deceive in order to create a false belief in another's mind. Further support for this conclusion was found in a follow-up study which showed that despite failing a standard false belief task, three-year-old children could correctly predict the false belief regarding the whereabouts of the hidden treasure held by the adult (Hala, Chandler & Fritz, 1991). Additionally, young children can comfortably hide their emotions in order to actively engage in deception (Lewis, Stanger & Sullivan, 1989). In this study, 87% of three-year-old children, although asked not to, did look at a toy while an experimenter left the room. Subsequent interviews reported that only 38% of children admitted to looking with neither facial nor body movements differentiating the truth tellers from the deceivers. By definition, the ability to deceive must reflect an awareness of belief. The findings from these studies are therefore in accordance with the premise that between the ages of two to four years, children come to understand the concept of belief.

It has been argued that possessing a 'theory of mind' should not be identified solely with passing false belief tasks (Gopnik & Wellman, 1994). Moreover, the empirical validity of findings from investigations into the concept of belief in young children has

been debated. Controversy surrounds the age of onset regarding an understanding of belief and researchers, driven by methodological concerns, have demonstrated an understanding of belief in children much younger than previously envisaged. However, questions regarding the exact depth of understanding in children younger than four years persist (see Bloom & German, 2000).

Regardless of these issues, it is generally accepted that typically, by the age of four years, children have an impressive understanding regarding belief. They appreciate the representative nature of belief (Perner, 1991), they have grasped that beliefs can change and that their beliefs may differ from the ones held by others (Gopnik & Astington, 1988). Additionally, they can predict the actions of others based on false beliefs (Wimmer & Perner, 1983). However, it is important to note that knowledge acquisition in the domain of psychology does not stop once an understanding of belief has been achieved. In the next section a brief overview will be given of other psychological concepts that develop in later childhood.

## **2.5. Later Developments in the Domain of Psychology**

Although the domain of psychology develops throughout childhood and children continue to form a deeper understanding in this domain there is still relatively little research in this area. While children aged four already hold a sophisticated understanding of the mind that is not dissimilar to that held by an adult, it is acknowledged that there are differences. However, the differences are said to be 'quantitative' in nature and not radically 'qualitative' (Hala & Carpendale, 1997). In other words, children develop a more advanced level of understanding but this is based on the same initial foundations that they have at approximately four years. It has been argued that domain-general abilities may help children to develop a more 'adult like' understanding of intuitive psychology. For example, Perner (1991) proposes that 'second order' false belief reasoning (i.e. one person's mental states about other mental states) involves the increased ability to keep track of the number of recursions with regard to intentional states. This allows six-year-old children to understand that someone can have a belief about another's belief.

It has been argued extensively by Chandler and colleagues (for example Carpendale & Chandler, 1996) that an understanding of interpretation (i.e. the ability to understand

that people may draw different interpretations from ambiguous stimuli) is missing from the pre-school child's repertoire of intuitive psychological understanding. Others such as Perner and Davies (1991) disagree but it has been argued convincingly that the ability to understand that someone can be right or wrong, depending on the information they receive (as tested in the false belief task) is distinct from understanding that a difference in opinion can still manifest itself even if both parties receive the same information. For example, Chandler and Lalonde (1996) presented children, via a restrictive window paradigm, with a small area of a large picture, for example a 'pig'. They asked children if it was possible for two puppets, both receiving the same information, to form different beliefs about the large picture. Only children aged six to seven years could appreciate that when given an ambiguous stimulus there are multiple ways of interpretation. Likewise, McGhee (1979) has shown that it is not until this age that children can appreciate that a single event may be humorous to some but not to others. This and other work (e.g. Carpendale & Chandler, 1996; Pillow, 1991) suggests that an understanding of interpretation is complex and in the course of development arrives a few years later than an understanding of belief.

The role of 'personality traits' in shaping behaviour is also a more subtle psychological concept and it is not until the age of six that children appreciate that mental thoughts about the world can be person-specific, enduring and consistent across situations (Heyman & Dweck, 1998; Heyman & Gelman, 1998; Miller & Aloise, 1989). In addition, older children also have a deeper appreciation that the mind is an active interpreter and constructor of knowledge that can independently be thought of as having a 'mind of its own' (Wellman & Hickling, 1994). For example, children aged seven appreciate that the mind is never completely empty of thoughts, and that an adult sitting quietly alone may be experiencing inner mental images (Flavell, Green & Flavell, 1993; 1998). Only by the age of eight will children declare that people still 'think' whilst engaging in activities such as pretending, reading, listening and talking (Flavell, Green & Flavell, 1995; Lillard, 1993).

## **2.6. Summary**

Intuitive psychology encompasses the notion that the mind exists, the mind consists of various mental states and that there are various causal links between an individual's mind, external environments and actions (Lee & Homer, 1999). The previous sections

have outlined the key research findings from work on intuitive psychological concepts in typically developing children. It has been demonstrated that from birth, infants demonstrate preferential attention to human stimuli and from as early as eight months of age clear signs of social interaction are evident (Wellman & Lagattuta, 2000). There is considerable support for typically developing young infants being 'spontaneous psychologists' (Karmiloff-Smith, 1992). At around 18 months, infants show an understanding of mental state concepts such as desire (Repacholi & Gopnik, 1997) and by the age of two years the ability to distinguish clearly between mental and physical phenomena is demonstrated by their engagement in pretend play (Leslie, 1987; McCune-Nicolich, 1981). During the pre-school period children rapidly acquire key concepts that pertain to the domain of psychology. These include an appreciation that seeing leads to knowing (Pratt & Bryant, 1990) and the ability to attribute mental states to oneself and others (Leslie, 1987). Later developments occurring between the ages of six to eight years include understanding that opinions can differ even if both parties receive the same information (Carpendale & Chandler, 1996) and that personality traits shape behaviour (Heyman & Dweck, 1998).

Discussions regarding children's acquisition of intuitive psychological knowledge often refer to studies that highlight a lack of understanding of psychological concepts in children with autism (see Karmiloff-Smith, 1992; Gopnik, et al., 2000; Wellman & Gelman, 1992). This chapter will therefore now turn its attention to empirical studies that have investigated intuitive psychology in children on the autistic spectrum. This work describes the difficulties experienced by this group in understanding the psychological world.

## **2.7. Intuitive Psychology in Children on the Autistic Spectrum**

As discussed in Chapter 1, autism is a condition associated with impairments in communication, social interaction and imagination (MRC, 2001). It has been claimed that the impairments in autism can be best understood in terms of a difficulty in understanding phenomena pertaining to the domain of psychology (Karmiloff-Smith, 1992), a difficulty which has been described as 'early occurring' and 'universal' (Baron-Cohen, 2000b). The remainder of this chapter will therefore highlight key research findings from work on individuals with autism during infancy and childhood. Since the average diagnostic age for autism is five years (Howlin & Moore, 1997), infancy



work is limited and often based on retrospective interviews with parents. Nevertheless, this work will be presented since an appreciation of the lack of basic building blocks that arrive so early and so easily for typically developing children, forcefully highlight the importance of links between these foundational skills and subsequent knowledge acquisition.

## **2.8. The Absence of Basic Building Blocks**

Many of the building blocks discussed earlier with respect to typically developing children are impaired in children with autism. For example, infants with autism do not preferentially attend to faces (Osterling & Dawson, 1994) or human auditory stimuli (Karmiloff-Smith, 1992). Moreover, it has been shown that children with autism do not often make eye contact with their caregiver (Arbelle, Sigman & Kasari, 1994). However, it has been argued that children with autism do not actively avoid the eye region. Instead it has been proposed that they are simply unaware of the significance of the eyes and of eye contact thus do not seek this type of engagement (Frith, 1989). Infants with autism also display a diminished range of emotional expressions and find it difficult to interpret them in others (Sigman, Ungerer, Mundy & Sherman, 1987; Weeks & Hobson, 1987). For example, when presented with pictorial stimuli and asked to 'point to the one that is happy/sad', children with autism performed poorly (Jennings, 1973 cited in Hobson, 1991). In fact, even those with high-functioning autism have difficulty in identifying complex affective states such as surprise (Baron-Cohen, Spitz & Cross, 1993; Hobson, 1986).

Children on the autistic spectrum rarely show spontaneous imitation behaviours (Sigman & Ungerer, 1984; Sigman et al., 1987). When tested on a battery of imitation tasks including mouth opening, tongue protrusion and hand opening, children with autism performed more poorly than a group of typically developing children and a group of children with Down syndrome (Dawson, Meltzoff, Osterling & Rinaldi, 1998). Imitation provides a young infant with a rich source of information regarding one's own internal behaviour and that of others. It has been argued that the absence of this core ability in children on the autistic spectrum may have implications for the future development of their psychological understanding (Gopnik et al., 2000).



Typically developing infants around six to eight months have great motivation to engage in interactions with people but children with autism appear to lack this need for social referencing. They rarely (if at all) spontaneously engage in social interactions and studies have shown that a lack of joint perspective taking skills best discriminated children with autism from a mental age [MA] matched group of typically developing children (Mundy & Sigman, 1989; Rogers & Pennington, 1991). In fact, deficits occur in many joint-perspective taking abilities and this feature is common in infants who subsequently receive a diagnosis of autism (Baron-Cohen et al., 1996; Sigman et al., 1987). Not only do children with autism fail to understand that people have a perspective that can be shared or directed, they also do not try to attract or direct others attention to objects in their environment. They rarely use pro-declarative pointing (Baron-Cohen, 1989b) and make use of hand leading instead. However, unlike children with hearing impairments, they do not combine looking at the person they are hand leading with looking at the object in question (Siegal, 1996a). Additionally, in contrast to children with speech impairments, children with autism rarely use gestures to share emotional experiences (Dawson et al., 1998; Sigman, Mundy, Sherman & Ungerer, 1986).

In recent years, with the popularity of domestic camcorders and home videos, researchers have been able to analyse the early behaviour of children who have subsequently gone on to receive a diagnosis of autism. This work has reported that during the first and second years of life, children with autism, in contrast to typically developing children, clearly demonstrate at least five behavioural abnormalities. These impairments are primarily concerned with basic intuitive psychology and include poor social attention, lack of social smiling and an inability to use facial expressions appropriately (Adrien, Lenior, Martineau & Perrot, 1993). In addition, specific behaviours such as decreased attention to the faces of others, inability to display pointing behaviour and failure to orientate to one's name, have been identified (Osterling & Dawson, 1994).

Children on the autistic spectrum are also reported to have difficulty in distinguishing between physical and psychological phenomena. For example, when told about a girl who was thinking about a biscuit (mental) and one who was holding a biscuit (physical), they wrongly projected certain capabilities to the girl who was thinking

about the biscuit - such as asserting that she could 'eat the biscuit' (Baron-Cohen, 1989a). As already discussed, an ability to decipher between the physical and mental worlds is required to engage in pretend play and in contrast to their peers, children with autism exhibit very low frequencies of pretend play (Baron-Cohen, 1997; Ungerer & Sigman, 1981; Wing & Gould, 1978). Moreover, children on the autistic spectrum give few responses of a psychological nature and prefer to rely on physical means of construing phenomena. For example, in contrast to children with Down syndrome and typically developing pre-school children, children with autism fail to use expressive gestures to manipulate mental states. However, they freely use instrumental gestures in order to manipulate physical behaviour (Attwood, Frith & Hermelin, 1988). This avoidance of psychological responses was also evident in studies where children with autism were asked about the brain. In contrast to typically developing children, children with autism responded in accordance with behavioural functions and overlooked the presence of mental functions such as 'thinking'. It has therefore been suggested that "much of the autistic children's view of other people is limited to perception of behaviour rather than mental states" (Baron-Cohen, 1989a; p597).

With the absence of so many vital building blocks, it would not be surprising if children with autism were also less likely to develop higher level intuitive psychology concepts. This chapter will now focus on work that has investigated key psychological concepts in children on the autistic spectrum.

## **2.9. The Absence of Key Intuitive Psychology Concepts**

It is well documented that children with autism, regardless of age, have difficulty in reflecting on the contents of their own minds and on that of others (Baron-Cohen, 2000b). In the context of this thesis, they can be described as lacking intuitive psychological knowledge. Central to this claim is that the success or failure of children with autism on intuitive psychology tasks is distinguishable only by whether the task involves the domain of psychology or not. Thus it is important that children with autism have all the necessary domain-general pre-requisites needed to understand the task, such as competence in language, memory and motivation (Frith, 1999).

### **2.9.1. Perception and Knowing**

Basic perspective-taking skills have been demonstrated in children with autism. They can correctly position a doll in order for it to 'see' an experimenter. Furthermore, they can confidently state a doll's visual perception of a cube with opposing coloured faces (Hobson, 1984). Likewise, using only eye orientation as a cue, children with autism correctly identified a series of objects that were being viewed by an experimenter (Baron-Cohen, 1989b). These findings demonstrate that children with autism understand the function of eyes in seeing and can appreciate that the perception of an object is influenced by one's physical positioning in the environment (Baron-Cohen, 1989b). However, although the concepts of perception and knowledge are linked, children with autism have difficulty with the latter. They find it difficult to understand the premise 'seeing leads to knowing' (Perner, Frith, Leslie & Leekham, 1989). In fact, they cannot comprehend what it is to 'know' or 'not know' something. For example, when given a story about two characters, one who looks inside a box and one who touches a box, children with autism perform at chance level when asked to declare 'which one knows what's in the box?' (Baron-Cohen & Goodhart, 1994). In a similar vein, children with autism cannot separate what they know about the world and the physical appearance of it. A study has shown that in contrast to typically developing children aged four to six years, children with autism fail appearance-reality tasks. For example, even after examining a stone that looked like an egg, children with autism responded similarly to the appearance question ('what does it look like?') and the reality question ('what is it really?') by declaring that it looked like and really was an egg (Baron-Cohen, 1989a).

### **2.9.2. Desire**

Children with autism do spontaneously produce linguistic terms related to the concept of desire in their speech (Tager-Flusberg, 1993). Additionally, some studies have reported that children with autism have an understanding of desire in line with their MA (Baron-Cohen, 1991; Tan & Harris, 1991). However, when asked to reason about a situation where the concept of desire is implicit in the context, children with autism were shown to be impaired. It has been concluded that children with autism may have a limited understanding of desire. Their understanding appears to be based on the concept that people like different things and are happy when they get them. However, a deeper understanding of desire, involving issues such as desires being/not being

satisfied and desire change, is beyond their grasp (Phillips, Baron-Cohen & Rutter, 1995).

Although it may be easier for children with autism to reason about desire than other psychological concepts such as belief, it would appear that their understanding is still not intact (Phillips et al., 1998). One potential explanation for this impairment is that children with autism have difficulty-using eye gaze to communicate information about a person's desire. For example, one study introduced children with autism to a character named Charlie who was clearly depicted as looking towards a certain brand of confectionery. They were asked to declare, out of a choice of four, the sweet that Charlie wanted. Results showed that in contrast to typically developing four-year-olds, children with autism consistently responded in accordance with their favourite sweet and clearly failed to infer Charlie's desired choice (Baron-Cohen, Campbell, Karmiloff-Smith, Grant & Walker, 1995).

### **2.9.3. Belief**

There has been a considerable amount of work investigating the concept of belief in children with autism. The failure of this group to understand belief has been shown experimentally in a wide number of studies using different paradigms (among others, Baron-Cohen et al., 1985; Leslie & Frith, 1988; Perner et al., 1989). On the basis of this work it has been concluded that children with autism simply cannot grasp that different people can hold different beliefs. It is important to note that studies never show a total failure in the autistic group or a 100% success in the control groups. An element of chance will always affect an individual's performance, as will factors such as experience and motivation (Frith, 1999). For example, of the 25% of high-functioning children with autism who tend to pass, most have a minimum verbal MA of five years and six months together with a minimum chronological age [CA] of 11.6 years (Frith & Frith, 2000), however, this criterion does not guarantee success (Leslie & Roth, 1993). It is the purpose of this section to explore these research findings and raise some of the methodological concerns and associated issues pertaining to work on this concept.

Baron-Cohen et al. (1985) were the first to demonstrate that children with autism had a difficulty in comprehending the nature of false beliefs. Using the 'Sally/Ann task' they found that children with autism (with an average CA of 11 years) performed less well



than both a group of typically developing four-year-olds and a group of children with Down syndrome (of similar CA but with a lower non-verbal and verbal age). The failure of the children with autism cannot be attributed to general task demands because they correctly asserted that Sally put the marble into her own basket, in a memory control question. Additionally, they knew that the marble was currently under the box, passing a reality control question. Therefore, despite the ability to comprehend many parts of the task, they failed to infer the presence of a false belief held by 'Sally' on her return, responding instead only on the basis of what they themselves knew. Similar results have been found in tasks using the unexpected contents paradigm. For example, in contrast to a control group, children with autism fail to reason that a person viewing a tube of Smarties for the first time would believe that the contents of the tube would contain Smarties. This was despite the children with autism being older and having a higher mean verbal age than a comparison group of children with language impairments also tested on the same task (Perner et al., 1989).

As outlined in previous sections, with respect to false belief tasks work has shown minor modifications can allow three-year-old typically developing children to reason correctly about false beliefs (German & Leslie, 2000; Surian & Leslie, 1999). These findings have helped shed light on what is (not) going on when children with autism are faced with these tasks. It appears to be the case that failure among three-year-olds may occur for different reasons. For example, studies have shown that failure among this group may be attributable to general task demands such as memory rather than reflecting a cognitive deficit in intuitive psychology (Surian & Leslie, 1999). In children with autism, however, failure continues to occur even when task demands are reduced and, this failure is also present in individuals with high-functioning autism (Baron-Cohen, 1989b).

A proportion of individuals with high-functioning autism or Asperger syndrome are able to pass false belief tasks (Baron-Cohen, 2000b) but their success occurs at a much later CA than found in typical development (Happe, 1995). It has been suggested that they may pass not because they have a theory of mind, but because of the employment of compensatory strategies based on general reasoning abilities developed with age (Leslie & Roth, 1993). Thus their perceived 'understanding' will be piecemeal and not generalisable to different contexts (unlike that of a four-year-old). Supporting evidence



for this argument shows that in contrast to typically developing six-year-olds, individuals with Asperger syndrome who pass false belief tasks often fail more complex second order false belief tasks that involve comprehending that someone can have a belief about another's belief (Baron-Cohen, 1989c). Additionally, they have difficulty with more advanced ideas such as inferring complex mental states such as bluff and double bluff in story characters (Happe, 1994a).

On the whole, individuals on the autistic spectrum find it difficult to reason about false beliefs. This difficulty appears to be different from that experienced by children under four years and has been described as an inability to 'mind-read' (Baron-Cohen, 2000b). This claim is strengthened from results investigating deception, a concept intrinsically linked to belief. Studies have reported that children with autism have an inability to deceive (Oswald & Ollendick, 1989; Russell et al., 1991) and find it hard to decipher when someone is deceiving them (Sodian & Frith, 1992). For example, in a 'penny-hiding' game, children with autism found it difficult to comprehend that the game involves closing one's hand in order to deceive an observer regarding the whereabouts of the penny. Errors demonstrated by children with autism, and typical of children under the age of four years, included hiding the penny in one hand yet leaving the other open, and putting the penny out of sight whilst exclaiming 'it's in here'. As a result of these findings it was concluded that children with autism treated the game as if it were about keeping things 'out of sight' and 'not out of mind' (Baron-Cohen, 1992).

## **2.10. Summary**

Autistic spectrum disorders manifest themselves in a difficulty in understanding phenomena pertaining to the domain of psychology (Karmiloff-Smith, 1992). This impairment is 'early occurring' and 'universal' (Baron-Cohen, 2000b) and in infancy can be demonstrated by the failure to attend to faces (Osterling & Dawson, 1994) and human auditory stimuli (Karmiloff-Smith, 1992). The absence of imitation (Sigman & Ungerer, 1984; Sigman, et al, 1987), gaze monitoring and proto-declarative pointing (Baron-Cohen, Allen & Gillberg, 1992; Swettenham, 1996) is also a feature in the early development shown by many children on the autistic spectrum.

Children on the autistic spectrum also fail to distinguish psychological from physical phenomena (Baron-Cohen, 1989a), they rarely engage in pretend play (Baron-Cohen,

1997; Ungerer & Sigman, 1981; Wing & Gould, 1978), they fail appearance-reality tasks (Baron-Cohen, 1989a) and they find it difficult to understand the premise 'seeing leads to knowing' (Perner et al., 1989). Additionally, an understanding of concepts such as desire and belief, typically present by the age of four years, are impaired and in some cases even absent (Baron-Cohen et al., 1985; Phillips et al., 1995). Studies have reported that a proportion of high-functioning individuals with autism can understand basic intuitive psychological concepts. However, this understanding is limited and they have difficulty with, for example, more complex scenarios such as second order false belief tasks (Baron-Cohen, 1989c).

As a result of the findings from all the work reported above, children on the autistic spectrum have been described as lacking a 'theory of mind'. In contrast it has been claimed that typically developing children's domain of psychology comprises theoretical understanding i.e. children can predict, construe and explain in a coherent and principled manner. However, as already discussed in Chapter 1, the main theorists in the field offer different criteria for what is and what is not 'theoretical' knowledge. Consequently there is debate over the age at which children's understanding of psychological phenomena can be described as being truly theoretical. In addition, there are different accounts proposed for the pattern of atypical development in children on the autistic spectrum. This chapter will now briefly present a few cognitive accounts (previously discussed in Chapter 1) in order to address the notion of theoretical knowledge in the domain of psychology. Attempts will be made to present these positions with regard to typically developing children and children on the autistic spectrum.

### **2.11. Is the Domain of Psychology Theoretical?**

To link this research to one of the broader themes of this thesis the following section will discuss the theoretical status of psychological knowledge. Chapter 1 stated that a key characteristic of a 'theory' is the principle of coherence. Therefore, strength for the assertion that the domain of psychology is theoretical can be found in work showing that typically developing children's performance on intuitive psychological tasks is improved when tested in a conceptually coherent context (Gopnik, Slaughter & Meltzoff, 1994; Slaughter & Gopnik, 1996). For example, when three-year-old children who had previously failed a false belief task were given prior information regarding

desire or perception, as well as belief, they demonstrated improved false belief understanding when compared to children who had not received any training (Slaughter & Gopnik, 1996). This finding clearly highlights the coherent nature of the concepts contained within the domain of intuitive psychology. In a similar vein, consistency has been identified between impairments on tasks of intuitive psychology in children with autism, for example between poor performance on tasks of deception and false belief (Baron-Cohen, 1992; Oswald & Ollendick, 1989). These findings show that the domain of psychology is coherently impaired in children with autism and strengthens the claim that they do not have theoretical knowledge in this area.

Taking a modular perspective Leslie (1994) tends to speculate about core cognitive architecture rather than the status of theoretical knowledge per se. He asserts that children's intuitive psychological knowledge develops around the age of six to eight months with the activation of ToMM *system 1* (see Chapter 1). *System 1* represents the behaviour of Agents and according to Leslie and Roth (1993) this component is present in children with autism as demonstrated by their use of request-pointing and their understanding of desire. However, Leslie argues that ToMM *system 2* is biologically impaired in autism and as a result, they cannot develop a theory of mind (Leslie & Thaiss, 1992). He argues that the absence of ToMM *system 2* erodes the capacity for mental representations that are specific to intuitive psychology concepts such as pretending and believing. However, non-mental representations will remain intact in children with autism (Leslie & Frith, 1988; Leslie & Roth, 1993).

Karmiloff-Smith's (1992) RR model suggests that theoretical knowledge comprises explicit representations at phase E2/3. As a result, she claims that children's psychological knowledge is not theoretical until the age of four years. She argues that theoretical understanding has to be demonstrated by the ability to combine successful inferences and verbal justifications - just the sort of ability needed to reason about another's false belief. Before the age of four, Karmiloff-Smith (1992) suggests that children are employing E1 representations in order to, among other things, engage in pretend play. To recap from Chapter 1, E1 representations are not available to conscious access or verbal report and thus are not theoretical. However, Karmiloff-Smith does argue that they are the foundations on which theories of intuitive psychology are built. In the case of atypical development she suggests that across the

board 'normal' intelligence is not a prerequisite for RR to occur in a particular domain. As a result, the RR model envisages domain-specific deficits as a realistic possibility. Although Karmiloff-Smith fails to give a direct prediction regarding autism, she does claim that children with autism are unlikely to have a deficit in theory building per se. In accordance with her position, it may be the case that they have a representational deficit solely in the domain of psychology.

Advocates of the theory theory position presented in Chapter 1 (i.e. Gopnik & Meltzoff, 1997) posit that the domain of intuitive psychology comprises theoretical knowledge from birth. They emphasise the succession of progressively accurate conceptions of the mind present in children with age. They argue that this development can be attributed to the process of theory building and, at any point in time, children's understanding of intuitive psychology is theoretical (Gopnik & Wellman, 1994). In the case of autism, they suggest that children on the autistic spectrum lack an initial starting state theory of persons and subsequently this has a "cascading consequence for later development" (Gopnik et al., 2000: p63). In contrast to Karmiloff-Smith (1992), proponents of theory theory have recently suggested that, in addition, children with autism may have a deficit with theory building across all areas of understanding, rather than with theories of psychology in particular. They suggest that the inability to theorise, evident in children with autism, leads to failure in understanding the world in a deep, causal explanatory way (Gopnik et al., 2000) however, this suggestion requires empirical support.

## **2.12. Conclusions and Implications for this Thesis**

The literature review above aimed to show that sensitivity to socially relevant stimuli in infancy appears to function as a prerequisite for the development of core psychological concepts, such as desire and belief. Within this body of work, the manifestation of understanding in relation to 'belief' is considered to be a core development in children's domain of intuitive psychology (Lee & Homer, 1999) and generally, research supports the conclusion that a full understanding of the mind is not typically present until the age of four years (Perner, 1992; Perner et al., 1987). However, by utilising different methodology many researchers have reported task success in children aged three (among others, Chandler et al., 1989; Siegal & Beattie, 1991). These findings suggest that

three-year-old children's failure on standard false belief tasks is not attributable to a cognitive deficit in intuitive psychology.

Children on the autistic spectrum continue to experience difficulty in comprehending that different people can hold different beliefs well beyond the age of three-to-four years (Baron-Cohen et al., 1985; Leslie & Frith, 1988; Perner et al., 1989). Failure on false belief tasks in children with autism also occurs even when task demands are reduced (Surian & Leslie, 1999) and are also evident in high-functioning individuals with autism (Baron-Cohen, 1989b). Findings from this work point to the presence of an impairment in the domain of psychology that impinges developmentally on a wide number of abilities, from early social skills such as imitation to more advanced concepts typically present in the pre-school period. Pertinent to this claim is that success or failure of children with autism can only be distinguished from that of typically developing children by whether the task involves the domain of psychology or not (Frith, 1999). Therefore, an essential consideration for the studies reported in this thesis is that children with autism display the necessary abilities in language, memory and motivation needed to understand the task.

Some authors suggest that with respect to the cognitive foundations of autism there is only a deficit in the domain of psychology (e.g. Karmiloff-Smith, 1992; Leslie & Thaiss, 1992). If autism does result from specific deficits solely in the domain of psychology, then a demonstration of competence in another domain would provide strong supporting evidence for the domain-specific account of cognitive development. In an initial attempt to explore these issues the next chapter, Chapter 3, will review the literature concerned with the understanding of intuitive physics in typically developing children and children on the autistic spectrum.



## CHAPTER 3

# INTUITIVE PHYSICS: UNDERSTANDING IN TYPICALLY DEVELOPING CHILDREN AND CHILDREN ON THE AUTISTIC SPECTRUM

### 3.1. Aims of this Chapter

The purpose of this chapter is to present research findings from work investigating children's understanding of physics. Many argue that intuitive physics is situated alongside intuitive psychology as a core domain of cognition (i.e. Baron-Cohen, 2000a; Wellman, Hickling & Schultz, 2000) and, as will be shown, the initial acquisition of physical knowledge has been linked to innate mechanisms. In a similar way to the previous chapter, this chapter will present experimental work with young infants that has identified evidence of a number of early building blocks in the domain of physics. Likewise, it will be argued that these support the subsequent development of core intuitive physical concepts.

In contrast to the literature on the development of core concepts in the domain of psychology (presented in Chapter 2), the literature on children's understanding of physics is very piecemeal and tends to focus on concepts in isolation from one another. Children's knowledge of physical phenomena has had attention from both educational researchers and developmental psychologists, with each discipline tending to approach the topic in different ways. The former is generally concerned with physical concepts taught in school, the latter is more concerned with the intuitive ideas that infants and very young children may have regarding the physical world. It is often therefore the case that educational findings relate to why children fail to grasp scientific physics concepts rather than intuitive physics per se (as distinguished in Chapter 1). In an effort to identify potential candidates for fundamental physical knowledge, both fields of research relating to children's physical understanding will be explored. As well as attempting to identify core concepts, this chapter will also attempt to give an overview of what is known about the development of children's understanding concerning each. However, due to the vast volume of work in this area, this review is necessarily selective. Despite many areas having been investigated, no attempt has been made to

try and integrate work on areas of physical phenomena into an organised structure in the way for example, Wellman (1990) has in the domain of psychology. As a result, this chapter imposes a new structure on the literature on children's understanding of intuitive physics. It will be argued that in broad terms, the majority of research in the domain of physics falls into three main strands. The first is concerned with physical objects and their movement, the second with prevalent characteristics of objects, and the third with how physical/mechanical things work.

As well as presenting findings from research on typically developing children, this chapter will also examine the ability of children on the autistic spectrum to reason about phenomena relating to the domain of physics. This work will be scrutinised in order to investigate the assertion that children with autism can reason effectively (and possibly even exceptionally) in this domain.

### **3.2. Introduction**

From an early age children interact with the physical world. For example, they lift, push and roll objects of various shapes and weights, they toss and catch balls and in general, they exhibit great competence with these activities. Understanding pertaining to these events can be described as intuitive physics. Adhering to the characteristics of a domain presented in Chapter 1, the existence of a domain of physics has now been supported by a number of theorists who assign to it a central role in the ability to reason about the world (e.g. Leslie, 1994; Wellman Hickling & Schultz, 2000).

In order to reason about physical phenomena children must appreciate that objects exist and, as a result, the 'object concept' has been identified as a core constituent of this domain (Wellman & Gelman, 1992). In a similar vein to work in the domain of psychology, basic building blocks pertaining to intuitive physics, such as the object concept, are believed to be present from birth (see Carey & Markman, 1999). However, this was not always considered to be the case, Piaget (1955) claimed that infants younger than four months could not differentiate an object's existence from their own. Moreover, although he postulated that infants aged six months do show some partial recognition that objects exist, he argued that they lacked the understanding of an object's enduring existence when out of view. According to Piaget, this lack of 'object permanence' continues throughout the whole first year of life. As Chapter 1 has pointed

out, Piaget put forward a theory of domain-general development as the mechanism underlying growth in understanding. He argued that later developments were a result of domain-general structural re-organisation. Accordingly, he proposed that it was not until the end of the sensori-motor phase of development (at two years) that children fully develop an understanding of object permanence. With respect to physical causation, Piaget (1954) proposed that it was not until approximately 12-to-15 months that infants are able to understand that objects can behave independently from their own actions. In fact, he argued that a fully representational understanding of causality emerges at 18 months and it is only then that an infant can act upon an object in the physical world and observe the effect in a non-egocentric fashion.

In sharp contrast to Piaget's theory, more recent theorists maintain that children have an early conception of physical properties that is the result of innate pre-dispositions to view physical aspects of the world in a certain way. This viewpoint has emerged from the vast amount of work carried out on young infants and as a consequence, Piaget's (1955) idea that cognitive representations do not emerge until 24 months of age has long been disregarded. However, although the picture of what children know is becoming clearer, this chapter will highlight that disagreement still reigns in regard to the mechanisms that drive growth in infants' physical understanding. This disagreement relates to the differing theoretical positions that were discussed previously in Chapter 1.

### **3.3. Basic Building Blocks of Intuitive Physics**

Researchers taking a modular perspective assert that infants are born with substantial innate beliefs about objects. One proponent of this viewpoint is Elizabeth Spelke, a pioneer of modern infant research. She asserts that young infants are constrained from birth by a number of domain-specific principles that guide infants' perception and thus subsequent reasoning about objects and their movement. This implicit understanding is thought to constitute an early theory of objects, rather than merely a perceptual organisation of current sensory experiences (Spelke, 1988).

Spelke and her colleagues have reported implicit intuitive physics concepts in typically developing infants from a very early age (Carey & Spelke, 1994; Spelke, Breinlinger, Macomber & Jackson, 1992). According to this work, infants aged four months can

make specific assumptions about the nature of objects that cannot be attributed to experience. At the base of these assumptions are three key principles, often collectively described as 'core knowledge'. These constrain infants' perception of object motion and by extension, their reasoning about the physical world (Spelke, Phillips & Woodward, 1995). According to the principle of *cohesion*, objects are connected and bounded bodies and furthermore, these connected and bounded features remain intact throughout object movement. For example, many studies have demonstrated that infants expect all parts of an object to move on connected paths over space and time and that, unlike liquids, moving objects do not transform as they move (Spelke, 1988; Spelke, Von Hofsten & Kestenbaum, 1989; Spelke & Van de Walle, 1993). The second principle is that of *continuity*. This asserts that objects exist and move continuously on connected paths. Studies have shown that infants expect objects to move on the same connected path and that they never expect two objects to occupy the same place at the same time (Baillargeon & De Vos, 1991; Leslie, 1994; Spelke et al., 1992; Xu & Carey, 1992). Thirdly, infant reasoning is also guided by the principle of *contact*. This relates to the expectation that objects can only act upon each other if they have made contact. Numerous studies have replicated the finding that infants' understand that objects will act on one another if they come into contact but will not act on one another if there is no contact (Leslie, 1982; 1984; Spelke & Van de Walle, 1993).

It has been argued that a single system of knowledge encompasses these three principles of cohesion, continuity and contact (Carey & Spelke, 1994; Spelke et al., 1995). Furthermore, it has been argued that since this system is robust and general in infancy, the principles are not learned but innate. These concepts (or building blocks) are thought to serve as the basis for all subsequent learning about inanimate objects and are responsible for directing infants' attention to relevant physical elements in the visual field. This knowledge will eventually be elaborated as development proceeds but Spelke (1991) argues that core knowledge is neither abandoned nor replaced. As discussed in Chapter 1 modular accounts view development as the result of non-conceptual changes in information processing. Accordingly Spelke et al. (1992) have shown that the principles which determine infants' initial reasoning about physical entities in the world are central to the concepts held by adults. This, they argue, is evidence to support the view that cognitive development is not a process of



reorganisation or change but simply an enrichment of core cognitive capabilities that are present from birth.

Spelke and colleagues have shown that young infants do not understand all physical events. They suggest that the principles of gravity and inertia are learned since an understanding of these develops more slowly and in a somewhat piecemeal fashion compared to the principles contained in core knowledge (Kim & Spelke, 1999). For example, four-month-old infants do not appreciate the principles of gravity but by six months they start to show surprise when an object stops in mid air without support. The authors argue that this knowledge, while not present at birth, does result from innately specified mechanisms that require minimal experience with objects to induce understanding (Spelke et al., 1992).

Along similar lines to Spelke, Leslie (1994) proposes that infants have a specialised learning mechanism named Theory of Bodies Mechanism [ToBy], that enables them to create conceptual knowledge of the physical world (see Chapter 1). To support his position he has, through a series of experiments, shown that young infants have an early appreciation of mechanical/physical causation that can be attributable to ToBy. As a specific example, Leslie habituated two groups of six-month-old infants to either a) a film of a direct launching event where one object collides with and launches a second object, or b) a variation of this event whereby a time delay was imposed between the impact of the first object and the movement of the second. Infants were then shown the same event in reverse whereby film a) showed a reversal of the roles i.e. the cause is now the effect, and film b) showed no reversal of roles therefore providing no causal regularity. Leslie predicted that if infants understood mechanical causality then they should find the direct launching effect in reverse to be more interesting and, this is exactly what his results showed (Leslie, 1982; 1994; Leslie & Keeble, 1987).

In contrast to the strict modular accounts, Baillargeon and her colleagues suggest that infants are born with highly constrained, innate learning mechanisms that guide the acquisition of knowledge regarding objects (Baillargeon, Kotovsky & Needham, 1995; Baillargeon, 2000). This conclusion is a result of substantial work concerning certain aspects of physical events whereby a developmental pattern has been found to recur across ages and phenomena (for a review see Baillargeon et al., 1995). This work shows

that infants succeed in detecting some physical laws before others. According to Baillargeon this reflects their predisposition to form an 'all or none' concept about novel physical events whereby discrete and continuous variables, that with experience are subsequently found to affect the phenomena in question, are continually added into the child's developing concepts (Baillargeon, 2000). For example, when judging whether a box resting on a platform is stable, infants initially focus on the contact between the box's bottom surface and the platform thus treating symmetrical and asymmetrical boxes alike. However, by 12 months of age they have revised their concept to take into account the shape of the box (Baillargeon, 1986).

These modern accounts of development suggest that innate constraints lead to implicit understanding in infants younger than postulated by Piaget. For example, infants age three-to-four months can represent the existence of an object that is currently invisible thereby displaying evidence of 'object permanence' approximately eight months earlier than Piaget predicted (Baillargeon, Spelke & Wasserman, 1985). Furthermore, infants of this age were shown in the same study to demonstrate an understanding that objects are solid and substantial. This seminal work involved habituating infants to a display in which a screen continually rotated through 180° towards and away from an infant. Once the infant had habituated and no longer attended to the display, a box was placed in the path of the screen. Following this, they were shown one of two events: a possible event where the screen rotates until it makes contact with the box and comes to rest, and an impossible event where the screen rotates and appears to pass straight through the box. Results revealed that infants who were shown the impossible event attended to the display for longer thus indicating that they were surprised when the screen passed through the apparently solid object. This finding suggests that the infants expected the box to continue to exist even when occluded by the screen. Further work using this 'violation of expectation' technique has highlighted that not only do young infants represent hidden objects, but that they can represent some of their properties. For example, infants have demonstrated an understanding of whether an object is compressible (e.g. a wooden block versus a sponge) as well as whether it is taller or shorter than the screen (Baillargeon, 1987a; 1987b). Thus it appears to be the case that very young infants possess many of the same fundamental beliefs about physical objects as adults (Baillargeon, 2000).

As this section has shown, accumulating work demonstrates that very young infants have an implicit understanding about the nature of the physical world and most researchers in this area now agree with Anderson's assertion that "learning of intuitive physics start in the cradle" (1983; p252). From an early age infants have the building blocks that are necessary to understand that objects exist. In addition, they have intuitive ideas regarding the laws that constrain the movement of these objects and further, they actively seek causal explanations for physical events (Bullock, Gelman & Baillargeon, 1982; Shultz, Pardo & Altman, 1982; Smith, Carey & Wiser, 1985; Wellman & Gelman, 1992). As a result, by the time children reach the ages of three-to-four years they understand a great deal about the nature of physical phenomena.

### **3.4. Key Intuitive Physics Concepts**

The work to be presented below is concerned with children's developing understanding of physical phenomena. This field of research is very fragmented and in an attempt to draw together distinct areas of work this chapter will present work classified within three research strands. The first involves objects and their movement and comprises reasoning regarding the properties that govern object motion in the physical world, such as the causes of non-agent initiated events (Baron-Cohen, 1997; Baron-Cohen et al., 2001; Dennett, 1978). The second involves fundamental object properties such as the ability to reason about concepts such as size and weight. The third strand is associated with how things work and is linked to the term 'mechanics', encompassing ideas about how physical/mechanical objects work (Baron-Cohen et al., 2001; Disessa, 1998).

#### **3.4.1. Object Movement**

When reasoning about object movement, it is argued that children adhere to the idea that a cause will produce an effect by transmitting a force or restraint to it, or that a set of forces will cause trajectories, accelerations and so on (see Wellman & Gelman, 1992). Research investigating causal inferences will be discussed followed by a section on vertical motion and then by a section concerned with the effect of force on object movement.

### *Causal Contingency*

Research has shown that the ability to make causal inferences develops between the ages of three-to-four years (Das Gupta & Bryant, 1989; Gelman, Bullock & Meck, 1980) and is based on an understanding of four causal principles (Shultz et al., 1982). The first principle is based on priority i.e. a cause will precede (or co-occur) with an effect (Bullock & Gelman, 1979). The second principle is concerned with co-variation i.e. if an effect has multiple causes then the true cause will be the one that shows most regular co-variation (Shultz & Mendelson, 1975). The third is based on temporal contiguity whereby causes and effects must be linked by an intervening chain of contiguous events (Sedlak & Kurtz, 1981). Finally the fourth is based on the principle of similarity whereby the similarity of potential causes and effects must be used when making deductive inferences about physical causation (Goswami, 1998). These principles are employed by children as young as three years to reason about basic physical movement involving two-and-three-term causal chains (Baillargeon & Gelman, 1980; Shultz et al., 1982).

### *Vertical Motion*

Young children's intuitive theories about the nature of falling objects comprise the belief that 'all unsupported objects fall straight down' (Kaiser, Proffitt & McCloskey, 1985). This is clearly illustrated using a 'tube task' whereby children aged two-to-four years were shown a ball being dropped into one of three opaque tubes (Hood, 1995). Unknown to the children, the tubes were designed to form an interwoven maze and task difficulty was increased through adding more tubes and increasing the complexity of the interconnectedness. As a result, a reliance on the 'straight down rule' would lead the children to search in the wrong place. This is exactly what was found, with children aged two-to-four years consistently opting to search in the location directly beneath the point at which the ball was dropped. The presence of 'gravity errors' occurred at all levels of difficulty and continued to be present despite extensive training. Training did encourage the children to develop a growing understanding of the constraints of the tubes on the movement of the falling objects but the 'gravity error' recurred in children when tested using a different paradigm. These findings suggest that believing all objects fall straight down is an intuitive way of reasoning for children and, in most cases this intuitive understanding, albeit occasionally wrong, serves them quite well (Hood, 1995).



The tendency of young children to adhere to the belief that all objects fall straight down constrain their interactions with moving objects (Krist, 2001). This is shown when they are required to integrate information about objects that are moving forward and falling at the same time. This paradigm is evident in two cases: 1) rolling objects, such as a ball that rolls off a table, and 2) carried objects, such as bomb dropped by an aeroplane or a ball dropped by a person walking. Research using these exemplars has shown that young children ignore movement cues and focus on the absence of support thus predicting that the object will fall straight downward. Furthermore, they stick to this prediction even when the ball's horizontal momentum is made more salient (Kaiser, Proffitt & McCloskey, 1985). To some extent this understanding does develop with respect to rolling objects. In this case children first predict that the ball will move in an 'inverted L-shaped path' before correctly choosing a parabolic path at the age of eight years i.e. that the ball will move both forward and down at the same time. However, there are no age improvements in understanding the parabolic motion of objects falling from carried objects. In this case children aged eight still exhibit the straight down belief and it is not until the age of 12 that they identify a parabolic trajectory (Krist, 2001) and, even at a later age, their understanding is piecemeal and not evident in all situations. For example, when asked to predict the path of a 'bomb dropped from an aeroplane', only 65% of college students, the majority of whom had taken high school physics, answered correctly (Kaiser, Proffitt & McCloskey, 2000).

### *The Effect of 'Force' on Object Movement*

It is well documented that most children (and many adults) hold erroneous ideas about the nature of projectile motion that support a collection of ideas associated with 'impetus theory'. Impetus theory, first postulated by the Greek astronomer Hipparchus, is the idea that a force inside an object causes it to move. Although Newton laid to rest this idea in 1687 many people still find the notion of impetus intuitively reasonable. Surprisingly, young children aged four can correctly reason about object motion but children a few years older, when questioned about the same phenomena, repeatedly reply according to impetus theory. Therefore despite having implicit expectations of object movement from birth, and despite initially predicting the correct path of objects, many school age children hold 'misconceptions' about inanimate motion (Kaiser, McCloskey & Proffitt, 1986).

Inhelder and Piaget (1958) suggested that children have little idea of the forces that oppose motion. In their work, explanations given for cessation included the extinction of force imparted by the initial push, object fatigue, or by the objects tendency to rest. This study and one by Twigger et al. (1994) found that it is not until the age of 12 that friction and air resistance (i.e. drag) are considered to be appropriate explanations for the stopping of an object in motion. In a further attempt to investigate the concept of force, Howe (1998) showed children aged six-to-fifteen years a picture of a rolling ball and asked them 'what will happen to the ball's speed?' Results demonstrated increasing knowledge with age but young children gave non-physical responses with many related to impetus theory. They often predicted that an internal reduction of force would make the ball stop for example, one six-year-old child stated that the ball would stop when it got tired. Children of all ages referred to variable external forces that opposed motion, often asserting that 'the bumps and the cracks will slow it down'. However, the most sophisticated explanations, relating to constant external forces that oppose motion, rarely occurred in children under ten years.

Inherent misconceptions based on impetus theory have also been shown in relation to predictions made about the path a ball will take when it exits a curved tube. Across a group of pre-school children, primary aged children and adults, a U-shaped developmental curve was found. Children aged seven-to-twelve years consistently predicted that the ball would acquire a curved impetus and thus follow a curved path after it emerges from the tube (Kaiser et al., 1986). Only pre-school children and college students answered correctly that the ball will follow a straight path in accordance with the Newtonian principle that objects move in a straight line unless deflected by an external force. Interestingly, the researchers noted that the pre-schoolers were confused at the suggestion of a curvilinear path. The authors dismiss claims that the young children are employing a heuristic that all 'objects move in a straight path'. Instead, they conclude that children of this age have no overall theory of motion and answer on the basis of their experience. Kaiser et al. (1986) suggest that it may be the case that older children think about motion in a 'theoretical' way and their errors are a result of the systematic over-generalisation of a motion theory.

### 3.4.2. Object Properties

As well as investigations into physical movement, a small body of work has concentrated on children's understanding of the intrinsic properties of physical objects (such as weight). A key focus of this work has been on the development of children's ability to attend simultaneously to more than one property when trying to reason about physical phenomena.

#### *Material Kind*

With regard to material kinds, Smith, Carey and Wiser (1985) showed that young children aged three-to-four years identify 'kind' in terms of the most salient physical property of the material in question, for example, being heavy or light or being rough or smooth. This study also showed that pre-school children make use of gross generalisations between weight and material kinds, such as maintaining that all steel objects are heavy and all wooden objects are light. To illustrate, when presented with one piece of play-dough and one piece of clay of differing weight, and asked if the weight difference would still be maintained if the material was continually halved until very small, the pre-school children randomly responded in (what the authors describe as) an 'unprincipled manner'. Likewise, children aged five-to-seven years, who initially claimed that the clay was heavier, judged both materials when cut into small pieces, to weigh the same. It is not until children reach the ages of eight-to-nine years that they can correctly identify clay and play-dough as being different materials that continue to be so no matter how small the pieces are into which they are cut.

To further investigate children's understanding regarding material kinds, Smith et al. (1985) employed the 'grinder test'. This asserts that if materials are run through a grinder, they will still maintain their properties (i.e. sand in sand out: wood in wood out) however, this is not the case for objects (i.e. table in wood out). Results showed that all of the children tested aged between three-to-nine years knew that cut up objects were no longer the same kinds of objects but were the same kind of material. However, age differences in justifying answers about material kinds were found. For example, children aged four-to-seven years mentioned only perceivable properties such as 'it's shiny' whereas, older children aged seven-to-nine years gave a more sophisticated justification, defining a material kind as a core constituent of an object i.e. 'cutting does not affect the material'.

### *Size and Weight: Density*

Piaget & Inhelder (1974) reported that children employ a single concept encapsulating size and weight thus make their judgements about these concepts interrelated. In contrast, recent work by Smith et al. (1985) has shown that pre-school children have independent concepts of size and weight. Further, they argue that young children can make initial generalisations about these concepts, and that the concepts radically change over development.

In an extensive study, Smith et al. (1985) showed that at the core of the three year-olds weight concept is 'felt weight' as shown by their preference to judge weight by lifting objects. Young children see weight as a physical property of an object that causally affects the object's interactions rather than something intrinsically related to the object's size. For example, all children in this study judged that a heavy object (regardless of size) would make a foam rubber bridge collapse. Young children also failed to associate weight as a property of small objects. For example, children aged four-to-six years declared that a piece of styrofoam weighed nothing at all and, that the addition of one grain of rice would not make a pile of rice any heavier. On the other hand, older children, aged eight-to-nine years demonstrated a more sophisticated understanding of weight in which it was categorised as a property of matter. The majority of this age group stated that 'everything has to weigh something', correctly judging that a piece of styrofoam did weigh something and that one piece of rice would make a pile of rice heavier. Children of this age believe that if an object has matter it must have weight.

According to Smith et al. (1985), children's early concept of weight does not include the notion of density. In fact, their study showed that children aged three-to-four years have to cope with a massive intrusion of weight concepts into density judgements. It is only between the ages of five-to-seven years that the idea of 'heavy for size' was included in reasoning about weight. The notion of density has been further investigated using the floating and sinking paradigm. These studies have shown that many children intuitively adhere to the variable weight as being the key as to why objects float and sink and that the idea of relative density is not often entertained until approximately 11 years (Inhelder & Piaget, 1958; Laurendau & Pinard, 1962; Piaget, 1930). A study by Biddulph (1983) reported a range of variables associated with floating, the most common being lightness, having air inside, being of buoyant material and/or being



non-compacted. The variables commonly associated with sinking were being heavy, having no air inside, being solid and/or being absorbent. In a more recent study Howe (1998) reported that children aged between eight and twelve years mentioned an astonishing 135 variables associated with floating and 115 variables associated with sinking (80% of the children mentioned at least ten). Furthermore, the author concluded that no child mentioned a combination of variables that could be interpreted as an understanding of relative density, even although the oldest children in the study were at an age at which understanding had been found in other studies (i.e. age twelve, as in work by Piaget, 1930; see also Laurendau & Pinard, 1962; Piaget & Indhelder, 1958). In fact, no robust clusters were found in the data with regard to children aged eight-to-twelve years. However, between the ages of ten-to-eleven, irrelevant variables were decreasing and relevant variables were increasingly found in children's explanations.

### **3.4.3. How Things Work**

The need to integrate information about different object properties is central to understanding 'how things work'. Within the literature understanding of many mechanical items has been investigated but this chapter focuses on only two namely the balance scale and gearwheels as these illustrate examples of the physical concepts examined in studies contained in this thesis.

#### *The Balance Scale*

In order to reason about a balance scale children are required to integrate information about weight and distance. Studies employing this task have shown that young children can identify the physical features of pegs (i.e. weight, size, colour) that may (or may not) influence the workings of a balance scale. However, they have little understanding of the effect of spatial features (Amsel, Goodman, Savoie & Clark, 1996; Metz, 1993). For example, studies have reported that the judgements of pre-schoolers are based solely on the number of objects on each arm (i.e. weight). However, this is not due to lack of cognitive ability to understand more than one variable since they do not dismiss all other variables as non-causal. Rather, it seems to reflect children's rather piecemeal evaluation of the factors influencing a balance scale whereby they firstly reason about the physical properties of objects placed on the arm before expanding their understanding to include spatial features (Amsel et al., 1996).

In a comprehensive study, Siegler (1976) investigated the different rules that children employ in their judgements regarding which arm of the scale would descend when one variable (weight or distance) was held constant and the other varied. His results indicated that children used one of four rules (or five if chance guessing was included) whereby each emerging rule builds on fundamental components of the preceding one but includes additional information that contributes to a progressively more accurate solution. The majority of children aged five-to-six years exhibited Rule I considering the dimensions of weight and distance separately and always judged that the arm with the most weights would descend. Children exhibiting Rule II considered distance information but only when the same number of weights were present on each arm. Children aged 13-to-14 used Rule III whereby they considered both variables, but only when the two did not conflict. In fact, performance on such 'conflict-weight' problems (when one side had a greater weight and the other a greater distance) was no different to that expected by chance guessing. Only by the age of 16-to-17 was the movement towards Rule IV evident, as shown by the correct integration of weight and distance information. However, Wilkening and Anderson (1991) argued that Siegler's methodology led to the gross underestimation of children's ability to integrate information about two variables. When asked to balance a set of weights in accordance with both weight and distance variables, children aged nine (using Rule II in Siegler's study) were able to integrate information regarding both. However, young children still adhered to the intuitive belief that equal weight on both sides would allow the scale to balance.

### *Gearwheels*

Metz (1985) investigated children's problem solving in the domain of physics using a gearwheel task. This task involves presenting to children twelve round gears (alternatively known as cogs or wheels) of varying size and a Velcro board. Two of the gears are marked with a man and the children are asked to arrange the gears so that when a knob is turned clockwise, the men do 'feet first somersaults'. The solution to the task involves knowing the parity of gear elements between the marked gears. If there is an odd number then the two marked gears will turn in the same direction and if there is an even number then they will turn in opposite directions. However, if there is one connection with an odd number and one with an even number then the construction

will jam. This study found children under the age of twelve simply could not understand how to work the system efficiently.

### **3.5. Summary**

Children's reasoning about physical phenomena can be categorised according to three areas. The first area to be overviewed was an understanding of object movement. This showed that children aged three-to-four years can successfully reason about causality using the principles of priority, co-variation, temporal contiguity and similarity (Shultz et al., 1982). Young children also appear to have an inherent notion of gravity that allows them to appreciate that all unsupported objects will fall straight down (Hood, 1995; Kaiser, Proffitt & Anderson, 1985). However, young children have difficulty in reasoning about more sophisticated concepts and have little idea about the forces that affect object movement. Work has shown that they tend to rely on impetus theory to make predictions i.e. believing that a force internal to the object causes it to move/stop moving (Howe, 1998; Kaiser, Proffitt & McCloskey, 1985; 1986).

The second area of research reviewed concerned the intrinsic properties of objects. This work has shown that children aged three-to-four years focus on the most salient physical property of the object in question, for example, being heavy or light. Furthermore, young children make use of gross generalisations between weight and material kind, such as maintaining that all steel objects are heavy (Smith et al., 1985). Nowhere in children's early concept of weight is the notion of density (Smith et al., 1985). Using the floating and sinking paradigm it was found that children focus on the weight of an object to explain why it may float or sink. An understanding of relative density has not been found in children under ten years (Indhelder & Piaget, 1958; Laurendau & Pinard, 1962) and may not be even fully in place by the age of twelve (Howe, 1998).

The final area discussed briefly addressed the way objects work. The balance scale paradigm requires children to integrate information about weight and distance. Findings have shown that pre-school children focus on the number of pegs on each arm but have little understanding of the effect of spatial features (Amsel et al., 1996; Metz, 1993; Siegler, 1976). With respect to gearwheels, Metz (1985) found that it was not until

the age of eleven-to-twelve years that children could integrate the relevant physical variables to complete the task successfully.

### **3.6. Intuitive Physics in Children on the Autistic Spectrum**

Chapter 2 described the difficulties faced by children on the autistic spectrum in terms of their impairment in the domain of psychology. In contrast to this work, it has been postulated that children with autism have an intact understanding of intuitive physics (see Baron-Cohen, 1997; 2000a). In an attempt to explore this hypothesis, the remainder of this chapter will highlight key research findings on the understanding within the domain of physics in individuals diagnosed as on the autistic spectrum.

Studies implicating an intact understanding of intuitive physics arose as a result of the very many investigations there have been into the cognitive abilities of children with autism. However, apart from work showing that infants with autism can successfully understand object permanence (Sigman & Ungerer, 1981), there is little investigation into whether children on the autistic spectrum have the initial building blocks in the domain of physics that are assigned to typically developing infants. This endeavour has been made virtually impossible due to the age at which autism is usually diagnosed (see Chapter 1) and as a result, the research with children on the autistic spectrum tends to involve children above the age of four years.

It is important to note that at first, this research did not directly investigate physical understanding as this was simply a side issue in the exploration of the difficulty faced by this group in understanding psychological phenomena. Consequently, there are real differences in the nature of the concepts investigated in children with autism and the ones described earlier that feature in research with typically developing children. For instance, work on children with autism tends to relate to basic notions regarding the physical world (such as physical representations), rather than to their knowledge of explicit physical phenomena (such as motion). This is because many of the studies relating to children on the autistic spectrum are situated within the cognitive developmental literature as opposed to the educational literature. Within the field of cognitive development, the investigative effort is related to the differential understanding of intuitive physics and intuitive psychology concepts in children on the autistic spectrum. In general, the educational literature is often linked to concepts that



are studied at school and few studies include atypically developing children. As a result, the body of work focussing on physics concepts in children on the autistic spectrum is still in its early stages and comprises very different research approaches from those used to explore intuitive physics in typical populations. As a consequence, points of contact between this work and work with typically developing children are sometimes limited.

### **3.6.1. Evidence for Intact Understanding of Intuitive Physics**

Although comparatively few in number, some studies do suggest that children on the autistic spectrum exhibit a superior level of understanding in the domain of physics (see Baron-Cohen, 2000a). Three main areas of work that will be presented subsequently in this chapter support this assertion. The first area to be presented is concerned with family studies of children on the autistic spectrum. Secondly, a brief overview of work investigating how children with autism interact with physical objects will be introduced. Finally comparative studies exploring the differentiated relationship between intuitive physics and psychology will be examined. This area is the one most strongly associated with the argument for strengths in understanding physical phenomena in children on the autistic spectrum and thus will be given most consideration.

#### ***Family Studies***

It was mentioned in Chapter 1 that there is evidence for there being a heritable link in autism (i.e. Bailey et al., 1995; Bolton et al., 1994). As a result, it has been argued that if autism is attributable to genetic factors then one should expect a similar but milder cognitive profile in family members (Baron-Cohen, 2000a). On this premise, it has been argued that the broader cognitive phenotype of autism may be characterised by impairments in the domain of psychology coupled with strengths in the domain of physics (Baron-Cohen, Wheelwright, Stott, Bolton & Goodyer, 1997). Support for this argument comes from evidence that parents of children with autism demonstrate mild but significant deficits on adult intuitive psychology tasks (Baron-Cohen & Hammer, 1997). Additionally, studies have started to probe the links to the domain of physics in individuals who have a close relative with autism. For example, research into the occupational pathways of close relatives has revealed that fathers and grandfathers of children on the autistic spectrum compared to fathers and grandfathers of children

with other disabilities such as Tourette's syndrome, are over represented in occupations with a strong physics component. In fact, it was reported that 28.4% of children with an autistic spectrum disorder had at least one relative who was an engineer (Baron-Cohen, Wheelwright et al., 1997). These results were supported and extended by Jarrold and Routh (1997) who reported that although engineering was over represented in fathers of children with autism so too was medicine, science and accountancy. Along similar lines, one study has reported a six-fold increase in autism in families of students studying subjects in the sciences as opposed to the humanities (Baron-Cohen et al., 1998). These findings support the premise that genetic links may result in a mild form of the condition being evident in close relatives of children on the autistic spectrum.

### *Behaviour with Physical Objects*

It has long been noted that children on the autistic spectrum often display repetitive interests with phenomena of a physical nature. In his seminal 1943 paper, Kanner noted that the child with autism demonstrates excellent, purposeful and intelligent relations to objects whilst exhibiting virtually no relations to people (cited in Frith, 1991). Subsequent work in this area has charted a similar preference for physical phenomena in children with autism. For example, Wing (1969) found a greater attachment to objects in children with autism than in other diagnostic groups. Furthermore, it has been noted that the clinical literature describes hundreds of cases of children on the autistic spectrum who are obsessed with machines and other physical systems (Baron-Cohen et al, 2001). Among this group it is common to find strong interests with mechanical objects such as clocks, vacuum cleaners and washing machines (Hart, 1989) and with mechanical systems such as light switches (Baron-Cohen, 2000a). It has also been reported that children on the autistic spectrum often display a strong fascination with object movement such as spinning tops and the opening or closing of doors (APA, 1994).

In contrast to these accounts, it has recently been claimed that children with autism have difficulties relating to objects as well as to people and that their interactions with objects differ qualitatively from their typically developing CA matched peers (Williams, Costall & Reddy, 1999). This study documents that children with autism manipulate objects in an unusual way. They prefer to explore and inspect objects in close detail, often looking at an object, or a single part of it, for an extended period of time.

Consequently, the authors suggest that children with autism may be impaired in this area. However, an alternative explanation is that children with autism are profoundly interested in objects and simply wish to understand better how they operate. Support for this idea can be found in a content analysis of children's 'obsessions' reported by Baron-Cohen and Wheelwright (1999). It was hypothesised that if repetitive interests can in some way be reflected by cognitive mechanisms then children on the autistic spectrum may have interests that are not random with respect to content. In fact, they may show a preference for phenomena that is associated with their cognitive strengths. In line with predictions, results showed that children on the autistic spectrum have obsessions that cluster positively in the domain of physics yet negatively in the domain of psychology. It was reported that in a sample of 92 questionnaires completed by the parents of children with autistic spectrum disorders, 84% of children had obsessions in the domain of physics compared to 5% in the domain of psychology. These figures were in contrast to a group of children with Tourette's syndrome. In this group 61% was reported to have obsessions in the domain of physics with 18% in the domain of psychology. The authors link the strong physical content of obsessions in children on the autistic spectrum with the argument that they have an intact and perhaps superior domain of cognitive reasoning pertaining to physical phenomena.

Evidence that children with autism show a preference for reasoning in terms of intuitive physics has been shown in a recent study concerning different types of object movement (Bowler & Thommen, 2000). Initial findings indicated that children with autism could distinguish psychological and physical entities by correctly differentiating patterns of movement that characterise agents (animate) and non-agents (inanimate). However, when this was investigated in more depth, children with autism were shown to have difficulty in describing the actions of two animate agents when their interaction did not involve contact but they could reason appropriately about interactions that did involve physical contact. A new interpretation of these results is that even when reasoning about animate agents, children on the autistic spectrum may employ their physical reasoning system and when this cannot be employed (as in the no contact condition) they find any other interpretation difficult.

### *Comparative Studies of Intuitive Physics and Intuitive Psychology*

The uneven pattern of cognitive reasoning in children on the autistic spectrum is clearly evident when comparing performance on tasks that are similar in structure yet represent two different domains of knowledge. This was first noted by Leekham and Perner (1991) who administered a 'false photo task' (Zaitchik, 1990) to children with autism. This task was designed to be similar in structure to the false belief task from the domain of psychology (Wimmer & Perner, 1983) but focussed on physical representations rather than mental representations. In the false photo task a camera records a scene then an object is moved from position A to B. Findings from this study and subsequent replications (e.g. Peterson & Siegal, 1998) have shown that children with autism correctly identify the object that will appear in the photo. Thus they have an intact ability to understand the nature of physical representations created by a camera, in stark contrast to their poor performance on tasks of false belief. This latter paradigm involves a person viewing a scene then leaving and whilst absent an object is moved from position A to B. As discussed in Chapter 2 children with autism consistently predict that on return the person will look for the object in its present (but wrong) location. Studies such as those by Petersen and Siegal (1997; 1998) show that children with autism have an understanding of physical representations that is far more advanced than their understanding of mental states.

A study by Baron-Cohen, Leslie & Frith (1986) employed a picture-sequencing paradigm to directly compare intuitive psychology and intuitive physics. When instructed to arrange pictures into a pre-determined sequence, twelve-year-old children with autism were shown to perform poorly on intentional stories that required an understanding of a character's mental state. On the other hand, they performed significantly better than a group of four-year-olds and a group of children with Down syndrome, who had an average CA of 10 years, at sequencing physical causal sequences. The children with autism were also more likely to produce descriptive utterances in the physical condition in contrast to the intentional one. These results suggest that children with autism can utilise knowledge pertaining to the domain of physics but have little understanding of intuitive psychological concepts.

Some phenomena have characteristics and functions that relate to both psychological and physical phenomena, a prime example being the brain. Work has shown that



typically developing four-year-olds attribute mental functions to the brain (e.g. thinking, dreaming). Only much later, and sometimes not even by 11 years, do children fully understand that the brain is also necessary for physical behaviour, e.g. walking or running (Johnson & Wellman, 1982). Baron-Cohen (1989a) extended this work by asking children with autism (who had an average CA of 14 years) what they understood about the brain. He found that they were more likely to report physical functions pertaining to the brain. This was in contrast to typically developing five-year-olds and a non-specific developmentally disadvantaged group with similar CA, who both preferred to report mentalistic functions (the most common one being 'thinking'). By referring to the brain in terms of physical attributes, the authors suggested that children with autism were in fact giving more complex answers than the other two groups. On this basis it was suggested that they have a precocious understanding of physical phenomena. However, as they had a higher MA than the comparison groups in this study this conclusion is perhaps not fully warranted.

In a direct comparison study Baron-Cohen et al. (2001) revealed a striking contrast between understanding of intuitive psychology and physics in children diagnosed with Asperger syndrome. The study employed a psychology task that involved participants being shown photographs of the eye region before being asked to pick from a choice of four emotions the one that the person is thinking or feeling (adapted from Baron-Cohen, Jolliffe, Mortimore & Robertson, 1997). The physics task involved 20 multiple-choice questions depicting the everyday physical causal world including items on how things work, motion and balance. Comparison of performance on these two tasks revealed that in contrast to younger typically developing children (with lower MA), children with Asperger syndrome were impaired in basic psychological understanding. However, in comparison to a CA comparison group (with similar MA) they demonstrated superior performance when reasoning about physical phenomena. This study appears to offer strength to the claim that children with an autistic spectrum disorder show superior understanding in the domain of physics. However, it must be noted that the intuitive psychology and physics tasks in this study were not similar in structure or procedure therefore, any conclusion reached from a direct comparison of the two may be misleading.

### 3.7. Summary

There has been little investigation into whether children with autistic spectrum disorders have the initial building blocks pertaining to the domain of physics which have been identified in young typically developing children. Furthermore, there are real differences between the concepts researched and the methods used to investigate these concepts in children with autism and physics knowledge in typically developing children, making comparisons across the groups difficult. Nevertheless, some studies do suggest that children on the autistic spectrum exhibit a superior level of understanding in the domain of physics (see Baron-Cohen, 1997; 2000a).

Family studies have shown that many fathers and grandfathers of children with autism are more likely to be employed in occupations with a strong physical component such as engineering, the paradigm occupation for a cognitive profile that reflects strengths in the domain of physics (Baron-Cohen, Wheelwright et al., 1997). Direct work with children who have autism has shown that they are profoundly interested in objects and are very keen to understand how they operate (Williams et al., 1999). This may explain why it has been reported that they have obsessions that cluster in the domain of physics (Baron-Cohen & Wheelwright, 1999). Moreover, when asked to reason about animate agents, children with autism tend to use their physical reasoning system and if this cannot be employed find any alternative interpretation difficult (Bowler & Thommen, 2000). Empirical evidence used to support the assertion that children with autism can reason about physical phenomena includes reports that they can understand the nature of physical representations created by a camera (Wimmer & Perner, 1983), are good at sequencing physical causal pictures (Baron-Cohen et al., 1986) and are more likely to report physical rather than psychological functions when describing the brain (Baron-Cohen, 1989a). Moreover, using a multiple-choice task, it has been recently shown that children with Asperger syndrome demonstrate a superior understanding of many concepts in the domain of physics when compared to a CA matched group of typically developing children (Baron-Cohen et al., 2001)

This accumulating body of work suggests that children on the autistic spectrum have a predisposition to relate to physical phenomena. However, Baron-Cohen et al. (2001) point out that 'the brain basis of folk physics' remains unclear and this is the case for both typically developing children and children on the autistic spectrum. More detailed

research is clearly needed therefore to support these initial findings concerning physics knowledge in children on the autistic spectrum before work on the physiological and structural bases of these abilities can commence.

### **3.8. Is the Domain of Physics Theoretical?**

A central concern of this thesis is the theoretical nature of intuitive knowledge and in contrast to the research effort in the domain of psychology, theoretical physics knowledge is an under reviewed field. As a result, little speculation has been offered with respect to whether typically or atypically developing children have theoretical knowledge in this domain. For example, unlike the effort by Slaughter and Gopnik (1996) in the domain of psychology (see Chapter 2) no attempt has been made to see if performance on intuitive physics tasks can be improved if tested in a conceptually coherent context. In order to shed light on this issue this chapter will again present the three cognitive accounts of theoretical knowledge in typically developing children that were previously discussed in Chapter 2 with respect to psychological knowledge but this time in relation to the domain of physics. With the exception of 'theory theory', speculation will be necessary as to how the theoretical positions included in Chapter 2 might account for what is known about the profile of physical knowledge in children with autism.

Leslie's explanation for infants' sensitivity to physical causality can be explained by ToBy, the innate module that is specifically concerned with mechanical events (see Chapter 1). In Leslie's view ToBy allows young infants to reason about physical objects in a theoretical way. It achieves this by guiding the infants reasoning through the notion of 'Agency' which, in the case of ToBy, is wholly concerned with mechanical 'force' relations between objects (Leslie, 1994). This allows the infant to assume that when objects move they possess or bear force and, when objects contact other objects, they transmit, receive, or resist force. By deploying this 'force representational system', the ToBy module allows explicit information about the mechanical properties of objects and their events be made available to the infant (Leslie, 1994). Leslie does not make any conjectures about the presence of ToBy in autism and does not discuss whether children with autism have theoretical understanding of physical phenomena. His idea that cognition is served by two distinct modules has been linked to autism but in that it suggests that the module serving the domain of psychology is impaired in autism (see

Baron-Cohen et al., 2001). It would be plausible to suggest that ToBy is present among children on the autistic spectrum however this conjecture remains speculative.

As already stated, Karmiloff-Smith (1992) asserts that for knowledge to be theoretical it must be represented explicitly (phase E1 or higher). She reports that the understanding that reflects the physical building blocks reported in infants by for example Spelke, is not theoretical in status since it comprises implicit representations. She suggests that physical knowledge develops as a result of initial implicit information being redescribed into explicit representations. As a result, she postulates that the understanding evident in children's explicit theories often resembles the constraints and principles that operate during infancy. She demonstrates that in the domain of physics children's theories can curtail learning. She shows that they often treat what should be counter examples as anomalies and in some cases even invent or ignore data in order to maintain their theoretical commitments. With respect to autism, Karmiloff-Smith's position would assert that implicit representations pertaining to physical phenomena would need to be present for explicit theoretical knowledge to develop. If children with autism have theoretical physical knowledge beyond E1 then they should have conscious access to this knowledge and be able to report it verbally. This theoretical position remains as yet untested and will be a consideration of Study 3 reported in Chapter 6.

Gopnik and Meltzoff (1997) claim that by the age of 18 months children have a 'theory of appearances' which encapsulates the coherent web of properties associated with the properties of objects. They argue that this initial theory pertaining to the domain of physics allows young infants to understand the laws governing the movement of objects, properties of objects, the spatial relations between stationary objects and the laws that govern the perceptual relations between observers and objects. Thus contrary to Karmiloff-Smith (1992) they assert that young children have a highly structured understanding of objects, that can be described as theoretical. Moreover, they suggest that the changes evident in this understanding have the hallmarks of theory change. As already discussed in Chapter 2, Gopnik and Meltzoff (1997) suggest that children on the autistic spectrum have problems with theory building per se. They suggest that studies demonstrating successful reasoning in children with autism on tasks of intuitive physics are erroneous since the tasks employed may not be tapping theoretical



knowledge (Gopnik et al., 2000). They argue that the motivation to learn about the physical world in children with autism may be different from the 'theory-driven' nature of learning evident in typically developing children. Moreover, they suggest that children with autism prefer 'things' to people because they can be dealt with in an atheoretical way without any reference needed to their underlying structure. However, they offer no empirical evidence to support this assertion.

### **3.9. Conclusions and Implications for this Thesis**

Research in the domain of physics is very fragmented and tends to concentrate on specific physical concepts in isolation from one another. Very little attempt has been made to integrate research on children's ideas into a well-defined body of literature. Nevertheless, work has shown that intuitive physics makes its appearance early in typical development and encompasses knowledge of solid cohesive physical objects and the causal regularities they exhibit. These building blocks allow understanding to expand rapidly during childhood to include an understanding of many physical occurrences, including advanced causal mechanisms and concepts such as weight and size (see Wellman & Gelman, 1992). However, in contrast to the domain of psychology, it appears to be the case that explicit physical principles are more difficult for young children to grasp. With respect to many concepts, a full understanding does not develop before the age of ten years and in many cases, formal teaching may be needed (see Howe, 1998).

If cognition develops in a domain-specific way then a demonstration of competence in children on the autistic spectrum in a domain such as physics would provide strong supporting evidence for this position. However, although there is a large amount of literature on intuitive psychological concepts in children with autism much less is documented about their understanding of intuitive physics. The fact that research conducted with children who have autism differs in many respects to the research carried out on typically developing children in this area further complicates the picture. This is a result of the differing abilities of the two populations as well as the different research orientations adopted. This thesis will, however, in the next three empirical chapters attempt to extend the research on intuitive physics in children on the autistic spectrum by incorporating the concepts researched in the educational literature with respect to typically developing children. For example, Study 1, to be reported in the

next Chapter, investigates the understanding of a balance scale. Study 2 to be reported in Chapter 5, involves among other concepts projectile motion and Study 3, reported in Chapter 6, incorporates the concept of density and vertical movement. The findings from the work to be reported aims to help in the evaluation of the relative strengths of domain-specific accounts of cognitive development offered in Chapter 1. Additionally it may also contribute towards the resolution of speculation concerning the theoretical nature of the domain of physics.

## CHAPTER 4

### STUDY 1: INTUITIVE PSYCHOLOGICAL, PHYSICAL AND BIOLOGICAL KNOWLEDGE IN TYPICALLY DEVELOPING PRE-SCHOOLERS, CHILDREN WITH AUTISM AND CHILDREN WITH DOWN SYNDROME<sup>\*1</sup>

#### 4.1. Aims of this Chapter

There now exists a wide collection of evidence that shows typically developing children have intuitive understandings relating to the domains of psychology, physics and biology (Wellman, Hickling & Schultz, 1997; 2000). Additionally, there is now accumulating work investigating these three domains of knowledge in atypically developing children. Despite this there is currently a lack of research systematically comparing the development of children's understanding across these domains. For this reason, the study reported in this chapter will investigate concepts relating to the domains of psychology, physics and biology. In keeping with the aims of this thesis three contrasting groups of children were studied in order to explore the continuity and discontinuity of development across domains. Pre-school children were included as an example of typical development and are an age group where understanding is thought to be evident in all three domains of knowledge. Children with autism were included because as shown in previous chapters, numerous studies have highlighted a domain-specific deficit in intuitive psychology among this group (Wellman & Lagattuta, 2000) alongside an intact ability to reason about intuitive physics (Baron-Cohen, 1997; 2000b) moreover, it has recently been suggested that their intuitive biology is less well developed than that of typically developing children (Gopnik et al., 2000). Children with Down syndrome were included because they are thought to exhibit domain-general cognitive deficits (see Karmiloff-Smith, 1992) and, despite within-group variation, they do not usually progress beyond the cognitive capabilities of a typically developing six-to-eight-year-old in any area (Wishart, 1999a).

---

<sup>\*1</sup> The data from this study has been published in the British Journal of Developmental Psychology (see Appendix E)

#### **4.1.1. An Overview of Intuitive Psychology, Physics and Biology**

As described in Chapter 2, the domain of psychology entails an understanding of persons and their mental life including core infant knowledge such as shared attention (Mundy & Crowson, 1997) and developmentally higher-level knowledge such as personality traits (Heyman & Dweck, 1998). Chapter 3 described how the domain of physics is typically thought to encompass understanding of physical objects and their movement, including fundamental knowledge of objects that is present in infancy (e.g. Baillargeon, 2000; Spelke et al., 1992) and higher-level knowledge of, for example, density (Howe, 1998). As well as having core domains of psychology and physics, some researchers have identified knowledge pertaining to biology as constituting a third primary domain of understanding (e.g. Inagaki & Hatano, 2002; Wellman & Gelman, 1992; Wellman, Hickling & Schultz, 2000). This biological domain is thought to be concerned with plants and animals and their characteristics, encompassing basic knowledge about categories of living things (Atran, 1999) and higher-level concepts such as inheritance (Springer, 1999; Williams & Tolmie, 2000) and illness (Kalish, 1999; Williams & Binnie, 2002).

Research has shown that typically developing children possess knowledge in each of these three domains by the age of four years. However, although evidence suggests that the building blocks of intuitive physical and psychological knowledge are present in early infancy, there are questions over the age of onset of intuitive biological knowledge. Understanding in this domain is thought to arise developmentally later (Carey, 1985; Wellman & Gelman, 1992) and as a result of the differing developmental models charted in Chapter 1, debate reigns over the precise nature of the initial cognitive foundations. For example, Carey (1996) believes that the biological domain is not distinct at birth and instead emerges under jurisdiction from the domain of psychology. Others such as Keil (1994) and Inagaki and Hatano (1993; 2002) disagree and argue it constitutes an independent domain of knowledge from the start.

As already discussed, children with autism demonstrate difficulties in reasoning about phenomena in the domain of psychology (see Chapter 2). Moreover, it has been suggested that this deficit in intuitive psychology is exclusive to autism since when compared to children with Down syndrome who exhibited a lower non-verbal and verbal MA, children with autism performed more poorly on a task tapping the



psychological concept of belief (Baron-Cohen et al., 1985). However, other studies have shown that children with Down syndrome and other atypical developmental disabilities (such as Williams syndrome) perform at a level below typical pre-schoolers, and similarly to children with autism on intuitive psychology tasks (i.e. Tager-Flusberg & Sullivan, 2000; Yirmiya, Solomonica-Levi, Shulman & Pilowsky, 1996; Zelazo, Burack, Benedetto & Frye, 1996). Thus clearly there is a need for further research in this area.

Chapter 3 highlighted research revealing that children with autism can reason competently about physical phenomena. This is clearly illustrated when comparing their performance on a 'false photo' task and a standard 'false belief' task (see Petersen & Siegal, 1997; 1998). These two tasks are structurally similar but assess understanding in different domains. Results show that children with autism pass the intuitive physics task but fail the intuitive psychology task. However, evidence supporting intact intuitive physics in children with autism has been heavily reliant on the 'false photo' task and consequently more research is required to investigate how children with autism understand other physical phenomena. Additionally, whereas some intuitive psychology research has included comparison groups (e.g. children with Down syndrome) this has not been the case in relation to intuitive physics. As a result little is known of physics knowledge among other groups of atypically developing children. Further research is thus required to ascertain whether intact physics is particular to children with autism, and to investigate the development of this domain in children with other forms of atypical development.

Although the vast majority of research with children on the autistic spectrum is concerned with the domain of psychology, recently research has begun to consider the development of intuitive biology knowledge in children with autism (Gopnik et al., 2000). In a study of high-functioning children with autism in which factual biological knowledge and biological explanations were explored, the children were found to apply incorrect classifications when categorising living versus non-living exemplars. Furthermore, they referred to movement as a defining characteristic of living things more than comparison children and also referred to biological processes less than comparison children in their explanations for classifying an exemplar as a living thing. It was concluded that children with autism may "possess a less well-developed theory of biology than do typically-developing children" (Gopnik et al., 2000; p68). This

finding that intuitive biology may be limited among children on the autistic spectrum, while intriguing, requires further exploration. Research is required to examine whether difficulties with intuitive biology are specific to children with autism or whether they are also evident in children with other developmental disabilities (e.g. Down syndrome). Johnson and Carey (1998) showed that individuals with Williams syndrome had relatively intact factual biology knowledge compared to typically developing ten-year-olds but that their 'theoretical' knowledge was at the level of six-year-olds. However no comparison with children with autism was made in this study.

#### **4.1.2. Comparative Studies Across Domains**

The lack of cross-domain comparison within particular groups of children can be attributed in part to the assumption by some researchers that domains are independent from one another. It may also be the case that intrinsic methodological difficulties of constructing tasks that assess equivalent levels of understanding across domains have led researchers to avoid testing out such comparisons. Evidence also indicates that intuitive biology may develop over a different time course than intuitive physics and psychology, thus exacerbating the problems in designing age-equivalent tasks across the domains of psychology, physics and biology. Despite these difficulties, it is important to examine the independence of understanding across these domains to fully address fundamental questions concerning the origins and possible neurological foundations of domain-specific cognition.

Relatively few researchers have attempted comparative studies of intuitive psychology, physics and biology. However, one series of studies was conducted by Wellman, Hickling & Shultz (1997, 2000) who investigated typically developing children's explanations of events (e.g. movement) and concluded that young children could utilise causal reasoning from the three domains interchangeably and flexibly. In a similar vein, Peterson and Siegal (1997) examined the performance of different groups of children (deaf children, children with autism and typically developing pre-schoolers) on three tasks. Each task related to a separate domain of knowledge: psychology (false belief, Baron-Cohen et al., 1985), physics (false photo, Zaitchick, 1990), and biology (innate potential, Gelman & Wellman, 1991). Their results showed that pre-school children and children who were deaf from signing families performed better on the intuitive psychology task than children with autism and children who were deaf from non-

signing families. However all groups of children performed similarly on the physics and biology tasks.

#### **4.1.3. The Present Study**

To explore the characteristics of domain-specific knowledge pertaining to psychological, physical and biological phenomena in typically developing pre-schoolers, children with autism and children with Down syndrome, the structure of Peterson and Siegal's (1997) study was replicated. Similarities and differences within and between domains of knowledge were explored by employing three further tasks (one from each domain). The additional tasks were conceptually different to the ones chosen by Peterson and Siegal, to provide a more robust indicator of children's understanding within each domain.

As illustrated in Chapters 2 and 3, developmental data suggests that the process of knowledge acquisition within a domain involves some concepts being understood before others. For example, young children's early domain of psychology includes knowledge of desire, perception and emotion but does not include knowledge of belief. Likewise a four-year-old child's understanding of biology typically includes animals but rarely plants (Wellman & Gelman, 1992). The pragmatic approach taken to equate tasks in each domain in the present study was to identify tasks that are normally passed in typically developing children by the age of four. All tasks employed in this study were therefore of pre-school level but one task in each domain was chosen to tap slightly more sophisticated concepts than the other. It was expected that within the domain of psychology an understanding of perception would precede an understanding of false belief; within the domain of physics an understanding of false photo would precede an understanding of balance; and within the domain of biology an understanding of innate potential would precede an understanding of illness (Wellman & Gelman, 1992). In each case the latter task assesses more sophisticated knowledge within the domain in question.

It was hypothesised that the typically developing four-year-old children would pass the tasks set at pre-school level in each domain, with the children with autism showing impaired performance on the psychology and biology tasks but intact physics performance. Based on previous work (i.e. Baron-Cohen et al., 1985; Baron-Cohen,

1989b) it was expected that the children with Down syndrome would perform similarly to the pre-school children on the intuitive psychology tasks.

## 4.2. Method

### 4.2.1. Participants

The participants were 60 children from one nursery, three mainstream schools and four special schools covering a wide range of socio-economic catchment areas in Edinburgh and the Lothians. Informed consent was sought and ethical guidelines were followed (see Appendix A). The participants comprised three groups: 23 typically developing pre-schoolers; 19 children diagnosed with autism according to DSM IV or ICD-10 criteria; and 18 children with Down syndrome. Parents reported the diagnosis of children with autism and confirmatory checks were made with school records. Table 4.1 details the sample characteristics. All participants were administered the British Picture Vocabulary Scale [BPVS-II] (Dunn, Dunn, Whetton & Burley, 1997) to ensure that they had a receptive vocabulary [RV] above four years. This has been the measure of choice in a number of studies of children with autism (e.g. McGregor, Whiten & Blackburn, 1998; Petersen & Siegal, 1998; Perner et al., 1989).

Table 4.1: Number [N], mean CA, mean RV scores and associated ranges (years; months) of each diagnostic group participating in Study 1

Diagnostic Group	N	Mean CA (range)	Mean RV* (range)
Pre-schoolers	23	4;4 (4;1 - 5;0)	5;4 (4;2 - 6;8)
Autism	19	10;0 (6;11 - 12;0)	5;4 (4;0 - 7;7)
Down syndrome	18	13;1 (9;0 - 17;5)	4;3 (4;0 - 6;1)

\* BPVS-II



#### **4.2.2. Materials**

Published tasks were employed and every effort was made to maintain their original detail. However, these tasks were initially designed for use with typical populations and therefore some changes were essential. Two main additions were made to ensure consistency of task demands and to increase their appropriateness for use with atypically developing children.

Firstly, each of the tasks employed a 'reality control' question [RC] to establish that participants were attending to the task and a 'memory control' question [MC] to ensure that failure would not result from memory problems. The control questions were randomly presented before the test question [TQ]: previous research suggests that this will not facilitate performance (Zaitchik, 1990).

Secondly, to eliminate the need for verbal answers pictorial response options were designed to accommodate the preference for non-verbal modes of response in children with autism and to omit response biases due to short-term memory difficulties experienced by children with Down syndrome (Freeman & Hodapp, 2000). For each task, participants were randomly presented with three drawings and instructed to point to the correct answer. On all the tasks only one option was correct and therefore the level of success predicted through chance was 33%.

#### ***Psychology Tasks***

Perception: Slaughter and Gopnik's (1996) perception task was employed, with one additional change; a toy boat was used instead of a toy cat. Participants were introduced to a teddy bear and told that 'he is sleepy so sometimes he will nap and sometimes he will play' he was then placed under the table. While seated at a table participants were asked to view a green toy boat through a red filter (the boat looks black). They were then asked to move seats in order to view the toy boat from the opposite side i.e. not through the filter (the boat looks green). Following this, the teddy awakes and wants to play. He was placed in the first seat and viewed the boat through the red filter. Participants were presented with a drawing of a red boat, a green boat and a black boat and were asked to:

RC: 'point to the colour of boat that you see now when you are sitting in this chair'.

MC: 'point to the colour of boat that you first saw when you were sitting over there in that chair'.

TQ: 'point to the colour of boat that the teddy will see when he is sitting over there in that chair'.

False Belief: Baron-Cohen et al.'s (1985) 'Sally/Anne' test of false belief was employed. In the standard procedure a girl doll called Sally places a marble under a basket and leaves the room. Before Sally re-enters the room another girl doll moves the marble, placing it under a box. Participants were shown three drawings: a box; a basket; and a container. They were then asked to:

RC: 'point to where the marble is really'.

MC: 'point to where the marble was in the beginning'.

TQ: 'point to where Sally will look for her marble'.

### *Physics Tasks*

False Photo: This task was a version of Zaitchik's false photo task (1990) using a smaller, child-size Polaroid camera. After pre-training participants in the use of the camera (see Zaitchik, 1990), the experimenter introduced a baby doll and demonstrated it being placed in a toy bath, in a toy bed and in a toy pram. The experimenter then placed the baby doll in the bath and asked the participant to look through the window of the camera (at the baby in the bath) and take a picture. The picture that was produced by the camera was placed face down on the table. Once this was completed a mummy doll was introduced and took the baby out of the bath placing it in the bed. In line with Peterson and Siegal (1997) the furniture designated for use in the photograph was varied across all trials. Participants were presented with three drawings of the baby in the bath, the bed and the pram and were asked to:

RC: 'point to where the baby is now'.

MC: 'point to where the where the baby was when the camera flashed'.

TQ: 'point to where the baby will be in the in the photo'.

Balance: The balance task was adapted from Siegler (1976) who reported that five-year-olds respond on the basis of weight but nine-year-olds consider both weight and distance from the fulcrum. Pilot work with pre-schoolers conducted for the present study found that all used rule I with a small minority using rule II. As a result the three choices of responses given to participants were defined as weight (partially correct, rule I), weight and distance (fully correct, rule II) and wrong.

Participants were first introduced to 'naughty teddy' and told that he wanted to play. They were then pre-trained in the workings of a balance scale (a large wooden balance painted in primary colours) emphasising the four equally spaced pegs on either side and the four rings that were all the same weight. Participants were encouraged to put the rings onto the balance 'in all the ways you can think of in order to learn how the balance works'. After approximately three minutes the experimenter fixed the balance in place with a piece of wood. Participants were told that the balance scale would not move but that they had to think about how it would look without the piece of wood. The experimenter proceeded by placing two rings on each of the second pegs from the fulcrum. The 'naughty teddy' then swooped over the experimental material and 'messes up' the balance scale by moving two rings to the third peg from the fulcrum on the left-hand side of the scale only. 'Naughty teddy' rather than the experimenter made the transformation to reduce inferred experimenter demands (McGarrigle & Donaldson, 1974). Participants were shown three drawings of the balance scale: balancing; tipping to the right; and tipping to the left. They were then asked (to):

RC: 'has naughty teddy has moved the rings?'

MC: 'point to how the scales looked before naughty teddy messed them up'.

TQ: 'point to how the scales should look after naughty teddy messed them up'.

### ***Biology Tasks***

Innate Potential: This task was taken from Peterson and Siegal (1997) and is an adaptation of an original innate potential task devised by Gelman and Wellman (1991). Participants were read a story about a baby animal, born to one species but raised by another: "this is a picture of a baby animal (shown in a 'nondescript embryonic way'). Her name is Edith. This is her mother, the dog (a realistic drawing of a dog is shown). When she was a tiny baby, Edith went to live with a family of cats. This is the mother

cat and father cat (a drawing of male and female cat was displayed) who raised her like their own baby. She lived with these cats all her life until she was grown up and she never saw another dog again. Now Edith is all grown up". A realistic drawing of a cat, a dog and a horse were shown and the participants were asked to:

RC: 'point to the animal who gave birth to Edith'.

MC: 'point to the animal who raised Edith'.

TQ: 'point to the picture of Edith now that she is grown up'.

Illness: This task is based on work by Kalish (1998). He showed that typically developing children's understanding of illness causation develops over age from a pre-school deterministic theory of illness to a later probabilistic understanding of causation. Since this study included a number of older participants this developmental trend was taken into account and the three choices of responses given to participants were defined as deterministic (partially correct, rule I), probabilistic (fully correct, rule II) and wrong.

Participants were read a story accompanied by pictures: "this is Craig he is happy playing at home (a drawing of Craig is shown). One day his friend came over to play (drawing of Craig and his friend playing is displayed). His friend had a cough and a runny nose, his friend had the cold. Craig played with his friend and his friend sneezed on him (drawing of Craig's friend sneezing on him is shown). After a while Craig's friend went home (drawing of Craig waving goodbye is shown)". Participants were shown three drawings depicting Craig as not having the cold, maybe having the cold and definitely having the cold. Since the pictures were partly subjective the experimenter pointed to each of them in turn as the three randomly presented choices in the TQ were given.

RC: 'did Craig have the cold before his friend came over?'

MC: 'does Craig's friend have the cold?'

TQ: 'point to the picture of Craig after his friend goes home, will he not have the cold, maybe have the cold or definitely have the cold?'



### 4.2.3. Procedure

Participants were tested individually in a quiet setting. In light of Slaughter and Gopnik's (1996) point that performance on one psychological task may facilitate performance on another, the two tasks pertaining to each domain were never presented in sequence in order to reduce this potentially confounding effect. However, it should be noted that this possibility of reciprocal influence of task performance in psychology still remains, although to a lesser degree. Within this constraint tasks were administered randomly. Participants who failed two attempts at the control questions were excluded from the study. If participants passed both control questions in a task but failed to answer the TQ it was repeated one more time. All tasks were administered to a child on the same day, in a single session lasting between 10 and 20 minutes.

### 4.3. Results

Children were scored as correct on each of the six tasks if they identified the fully correct answer from a choice of three cards (i.e. mean score for each task is out of 1). Taking each domain of knowledge separately, children's initial scores were analysed in a task (task 1 vs. task 2)  $\times$  group (pre-schoolers, autism, Down syndrome) analysis of variance [ANOVA]. For each task post-hoc Bonferroni t-tests with the observed level of significance corrected to account for multiple comparisons were carried out. Additionally, percentage pass rates were analysed non-parametrically to assess performance against that which would have been predicted by chance using a binomial distribution (i.e. the McNemar test).

#### 4.3.1 Intuitive Psychology

For the domain of psychology there was a main effect of group ( $F(2, 57) = 20.08, p < .05$ ) and an interaction between task and group ( $F(2, 57) = 3.65, p < .05$ ). Exploring the main effect of group in more detail, one-way ANOVAs revealed significant group differences in both the false belief task ( $F(2, 57) = 20.16, p < .001$ ) and the perception task ( $F(2, 57) = 7.34, p < .001$ ).

Table 4.2 shows the mean performance of each group. Bonferroni post hoc t-tests showed that the performance of the pre-schoolers on the false belief task was significantly better than the children with autism and the children with Down syndrome ( $t(40) = 6.41, p < .001$ ;  $t(39) = 4.54, p < .001$ ). With regard to the perception

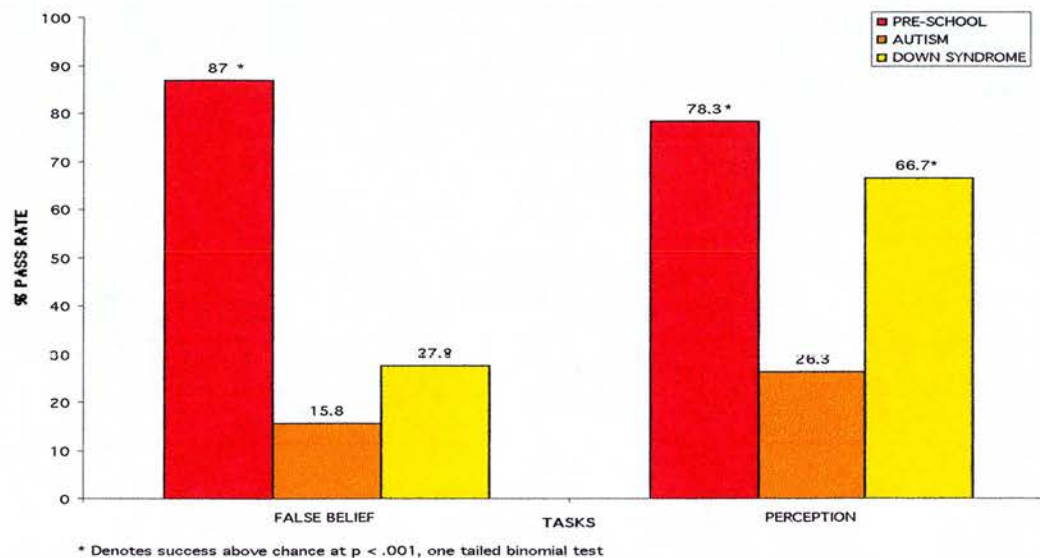
task, pre-school children and children with Down syndrome (mean = 0.67) performed significantly better than the children with autism ( $t(40) = 3.84, p < .001$ ;  $t(35) = 2.62, p < .001$ ). The observed interaction effect was due to the children with Down syndrome performing significantly better on the perception task than the false belief task ( $t(17) = 2.72, p < .01$ ) whereas, pre-school children performed well on both tasks and children with autism performed relatively poorly on both tasks.

Table 4.2: Mean performance scores for each task across participant groups

Diagnostic Group	Psychology		Physics		Biology	
	Perception	False Belief	False Photo	Balance	Innate Potential	Illness
Pre-schoolers	0.78	0.87	1.0	0.30	0.30	0.13
Autism	0.26	0.16	1.0	0.42	0.32	0.05
Down syndrome	0.67	0.28	0.94	0.56	0.39	0.33

On both tasks pertaining to the domain of psychology, Figure 4.1 shows the percentage pass rate of each group. Children with autism and pre-school children performed at chance level. Children with Down syndrome performed at chance level on the false belief task but above that expected by chance on the perception task ( $p < .001$ ). Additionally, the pre-schoolers performed significantly above the 33% level expected by chance on the false belief task ( $p < .001$ ) and the perception task ( $p < .001$ ).

Figure 4.1: Percentage of children in each group who passed each psychology task

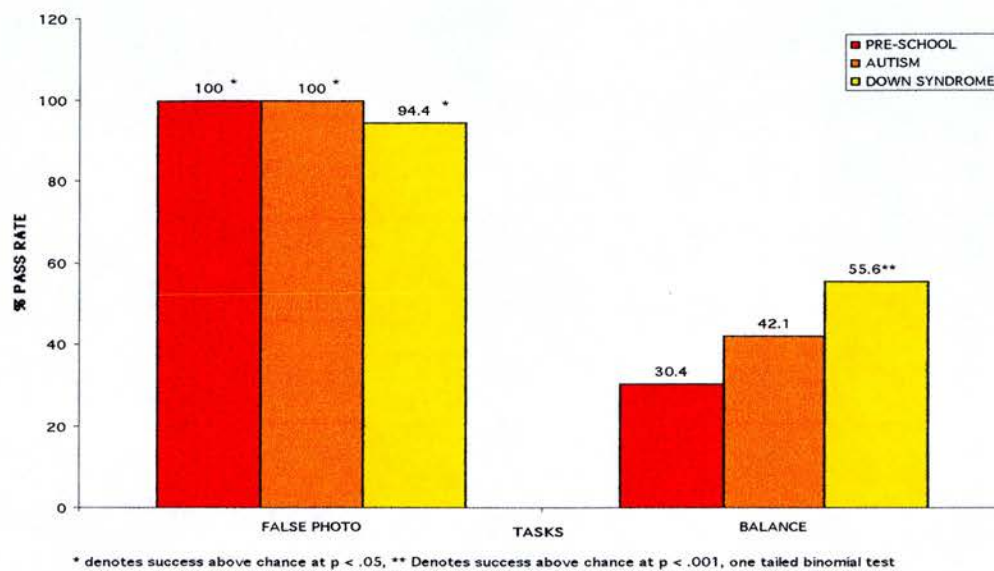


#### 4.3.2 Intuitive Physics

In relation to physics there was a main effect of task ( $F(1, 57) = 75.47, p < .001$ ) but no effect of group and no interaction effect. To explore the identified main effect in detail analyses were performed on each participant group separately. Post hoc Bonnferoni t-tests comparing mean task scores (see Table 4.2) showed significantly better performance on the false photo task than the balance scale task for the pre-school children ( $t(22) = 7.09, p < .001$ ) and the children with autism ( $t(18) = 4.47, p < .001$ ).

On both tasks of intuitive physics, Figure 4.2 shows the percentage pass rate of each group. Children in all three groups performed at ceiling level on the false photo task, well above the 33% level predicted by chance guessing (all  $p$ 's  $< .001$ ). On the balance task a correct response was granted if children chose rule II (fully correct). Analysis showed that children with Down syndrome were the only group found to have performed above that expected by chance ( $p < .05$ ).

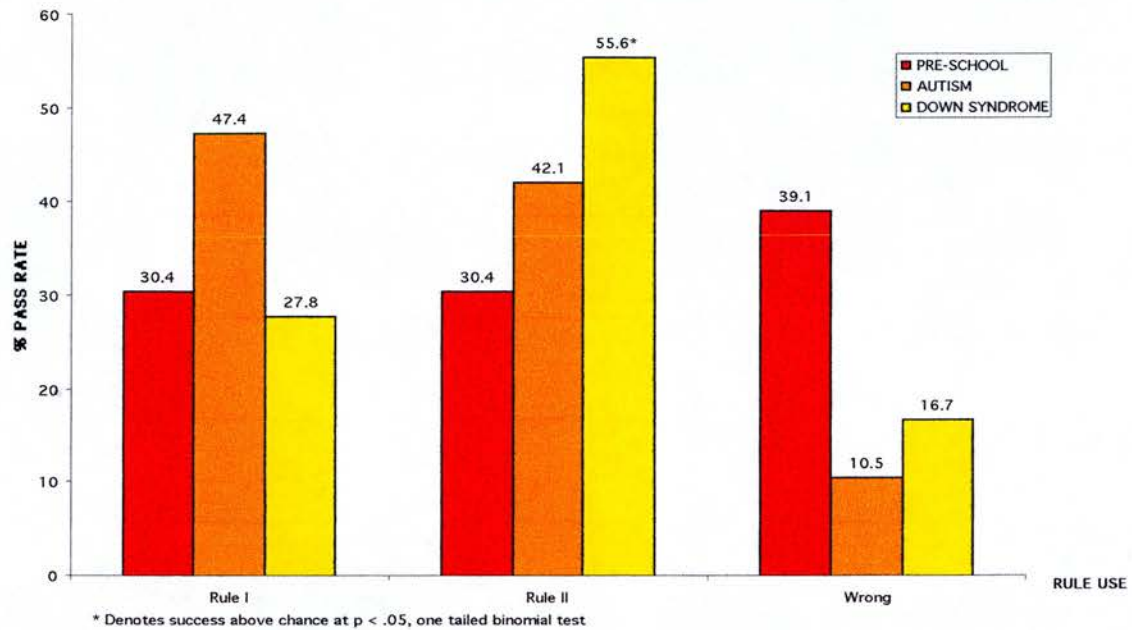
Figure 4.2: Percentage of children in each group who passed each physics task



The balance task was also analysed according to the developmental trend highlighted by Siegler (1976). As shown in Figure 4.3, responses did not differ to that expected by chance. However, the response patterns show that that children with autism were more likely to offer responses based on rule I (partially correct) whereas children with Down syndrome were more likely to offer responses based on rule II (fully correct). Additionally, children with autism were less likely to be wrong than the other two groups.



Figure 4.3: Percentage of children in each group applying different rules to answer the balance task

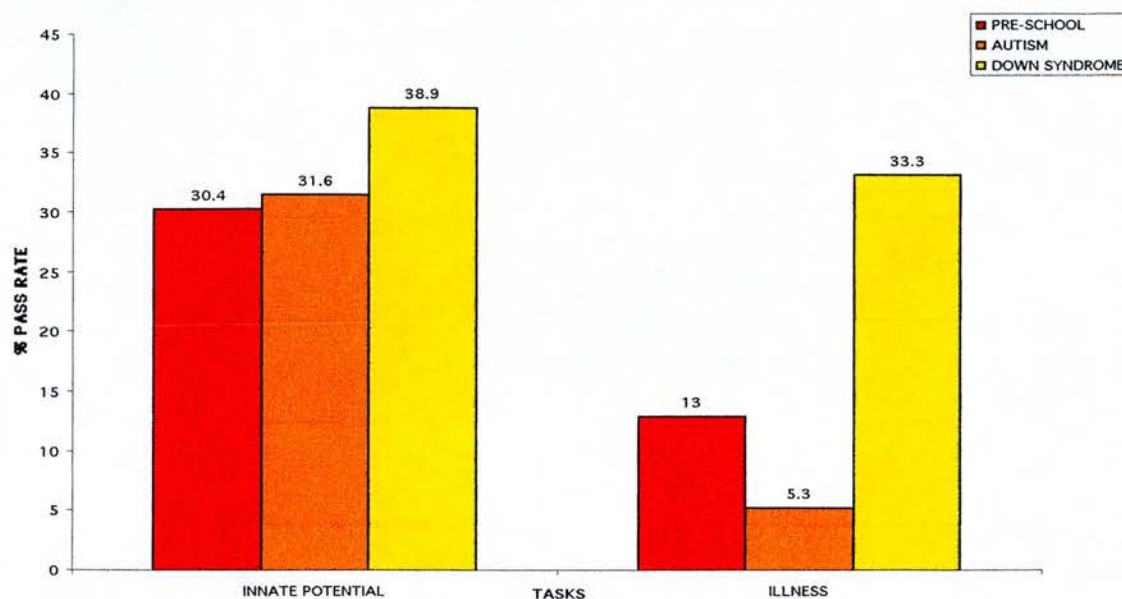


### 4.3.3 Intuitive Biology

In the domain of biology there was a significant effect of task ( $F(1, 57) = 5.72, p < .05$ ) but no effect of group or interaction effect. There was an overall trend for all children to perform better on the innate potential task than the illness task (see Table 4.2 for means). However, when groups were analysed separately this difference only reached significance in children with autism ( $t(18) = 2.54, p < .001$ ).

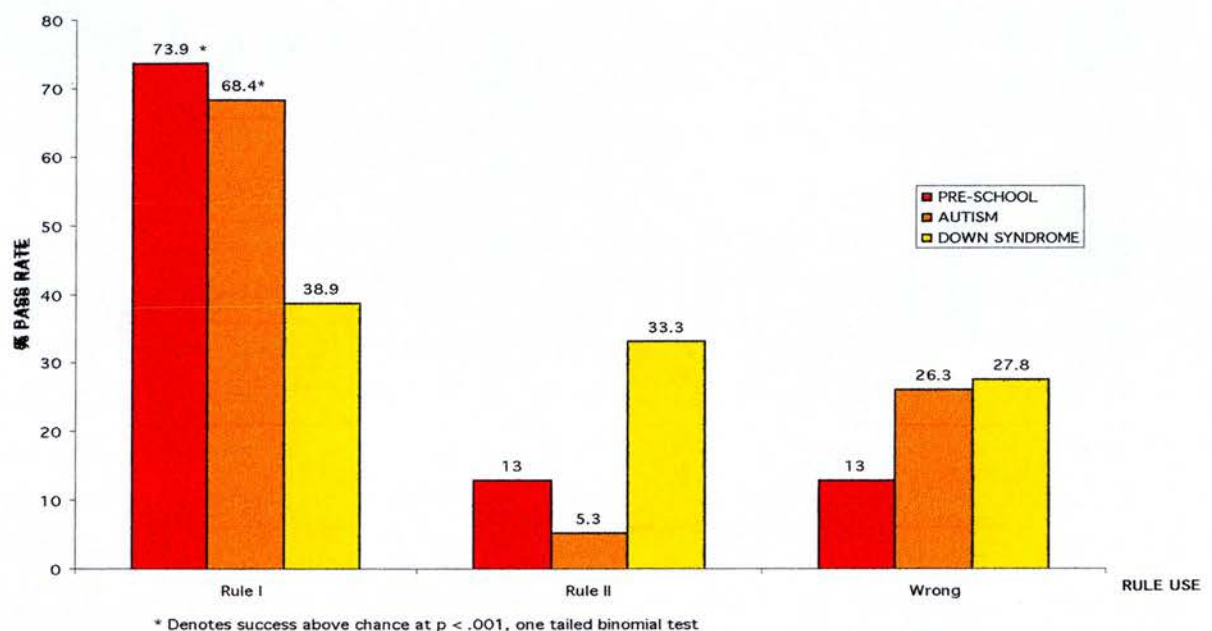
Figure 4.4 shows the percentage pass rate of each group on both tasks. Results revealed that no group displayed a better than chance performance on each task (level predicted by chance for each task is 33%).

Figure 4.4: Percentage of children in each group who passed each biology task



To explore in more depth the illness task data initial responses were re-coded taking into account the developmental trends identified by Kalish (1998). As shown in Figure 4.5 Pre-school children and children with autism were shown to judge illness causation as deterministic. Both groups responded on the basis of the partially correct rule I significantly more than predicted by chance guessing ( $p < .001$ ). The children with Down syndrome performed no different to that expected by chance but overall gave more rule II responses than the other two groups.

Figure 4.5: Percentage of children in each group applying different rules to answer the illness task



#### 4.4 Discussion

The present study found that pre-school children, children with autism and children with Down syndrome demonstrated different levels of performance in the domain of psychology whereas understanding in the domains of physics and biology was similar across participant groups. As predicted, the pre-schoolers performed according to the four-year-old level in all tasks. Additionally, children with autism revealed impaired performance in intuitive psychology. The finding that children with autism performed similarly to pre-schoolers (who had similar average RV as the children with autism) on intuitive physics tasks was taken as evidence that their understanding in this domain was intact although not superior. Contrary to that predicted, the performance of children with autism on intuitive biology was not impaired compared to the other two groups. The overall pattern of results for children with Down syndrome was not as predicted as they performed similarly to pre-schoolers on most tasks apart from the false belief task where they performed more poorly, and the illness task where their performance was randomly distributed across possible responses.

The results from the intuitive psychology tasks confirm the findings of previous research showing that typically developing pre-school children perform well on both the perception and false belief tasks. By contrast, children with autism performed consistently more poorly in the two tasks in comparison to pre-schoolers, despite being of higher CA and having a similar RV. A slightly different pattern of results was observed in relation to children with Down syndrome who performed well on the perception task but often failed the false belief task.

It is well documented that children with autism show poor performance on the false belief task (e.g. Baron-Cohen et al., 1985; Leslie & Thiass, 1992). However, their lack of success on the perception task contrasts with other findings (Baron-Cohen, 1989b; Hobson, 1984; Leslie & Frith, 1988). It is possible that these slight discrepancies may have resulted from the relatively high executive functioning demands of this task. The task required participants to inhibit reference to their own perception while answering a question relating to another's perception. As discussed in Chapter 1, executive functioning involves the ability to suppress a pre-potent but incorrect response while holding relevant information in working memory (Diamond, 1991; Pennington et al., 1997, Russell, 1997). Russell, Saltmarsh & Hill (1999) increased executive functioning demands in a 'desire' task and found this task adaptation reduced performance of children with autism to the same level as performance on a false belief task. Taken together, the results of the present study and those of Russell et al. (1999) suggest that executive functioning demands might play a role in the difficulty faced by children with autism on some intuitive psychology tasks.

In contrast to children with autism and pre-schoolers, children with Down syndrome demonstrated differential levels of performance in the two psychology tasks. They showed a clear understanding of perceptual role taking, supporting the results of previous research (Baron-Cohen, 1989b). However, in contrast to the results of Baron-Cohen et al. (1985), they exhibited great difficulty in understanding the standard false belief task. Indeed, despite the lack of any linguistic demands in the mode of responding, and despite subjects having a higher mean RV than the participants in Baron-Cohen et al.'s study (4.3 years and 2.11 years respectively), the performance of the children with Down syndrome was nearly equivalent to that of the children with autism. This poor performance had not been predicted and is hard to reconcile with the



findings of Baron-Cohen et al. (1985). However, other studies have highlighted that participants with Down syndrome are impaired in tasks of intuitive psychology, even studies which have included participants with a mean CA greater than 20 years (i.e. Yirmiya et al., 1996; Zelazo et al., 1996). These conflicting results could be the product of cross-study differences in the range of severity of impairments within the groups of atypically developing children tested. Another factor to be taken into consideration is that task success requires both cognitive ability and motivation to comply with task demands and succeed. Research has shown that children with Down syndrome may under-perform in testing situations due to motivational factors (Wishart, 1996b). In the present study considerable effort was made to develop interesting and enjoyable task materials while maintaining the veracity of the test but perhaps the motivational demands of the false belief task were comparatively high for this group. Some authors have stated that standard intuitive psychology tasks can be employed to compare performance across clinical groups (Charman & Campbell, 1997; Hughes et al., 2000) but more research is required to explore factors such as motivation that may confound findings of group differences in ability.

In relation to physics there was a clear difference in performance between tasks across all three groups of children. Performance on the false photo task reached ceiling level thus it was not surprising that performance on the balance task was poorer. Taking each task in turn, the high performance scores on the false photo task found in the present study are in contrast with previous work reporting much lower pass rates in typically developing pre-schoolers and children with autism (i.e. Leekam & Perner, 1991; Leslie & Thaiss, 1992; Peterson & Siegal, 1998; Zaitchik, 1990). The inclusion of non-verbal responses and the use of a small child-friendly camera may have facilitated performance in the present study. In addition, because most of the studies reporting lower levels of performance were conducted in the early 1990s the superior performance on the false photo task reported here may reflect an increase in children's knowledge and experience of using cameras over the past ten years.

A further issue is whether the false photo task is truly representative of the domain of physics. It might be possible for children to succeed on this task as a result of their procedural knowledge of using cameras rather than a deeper understanding of the nature or process of the representation. Likewise, Peterson and Siegal (1998) suggest

that the mechanistic nature of a camera draws attention to the encoding process and that the photograph provides a physical recording of the event thus facilitating responses. It remains unclear, therefore, whether the task methodology of handling a camera is responsible for the high success rates rather than a conceptual knowledge of basic physics.

All groups in this study performed more poorly on the balance task than the false photo task. Although there was no group differences, children with Down syndrome performed above the level expected by chance. Detailed examination of re-coded responses showed that for the pre-schoolers and children with autism rule I and II were used at chance level. Despite these results clear trends in the data were apparent. A higher percentage of children with autism than pre-schoolers passed the balance task and on the whole were less likely than the other two groups to be wrong. This could be taken as evidence, together with performance on the false photo task, that understanding of physics was relatively intact in children with autism when compared to pre-schoolers. However, children with autism were not found to have a superior understanding of physics as suggested by Baron-Cohen (1997; 2000a) since a higher number than that predicted by chance would have been expected to achieve rule II understanding given the considerable age advantage they exhibited. In order to investigate superiority in intuitive physics in children with autism a typically developing CA match would be required and consequently will be included in Studies 2 (Chapter 5) and 3 (Chapter 6) of this thesis.

With regard to biology there was a task effect whereby across all three groups of participants performance was better on the innate potential task than the illness task as predicted. The similar performance of the groups on each of these tasks is not in full agreement with Gopnik's (2001) assertion that biological understanding may be impaired or less well developed in children with autism but is in agreement with the findings of Peterson and Siegal (1997).

The findings in relation to innate potential resonate well with results showing no differences between children with autism and pre-schoolers on this task (Peterson & Siegal, 1997). However, the present study revealed lower performance scores across groups than those reported by Peterson and Siegal (1997) and in the original version of

the task (Gelman & Wellman, 1991). These discrepant results may be attributable to the materials used in this study. Great care was taken to follow the method of Peterson and Siegal (1997) but it is possible that minor differences could have influenced results. For example, in the present study the inclusion of a third response choice allowed for random guessing to be more fully identified, consequently the present results may differ from previous work but may be a more accurate reflection of children's understanding.

Turning to the illness task, initial analyses showed that overall children performed at a lower level on this task than the innate potential task. More detailed analyses of the re-coded data showed that pre-school children and children with autism were deterministic in that they chose rule I significantly more often than expected by chance. However, children with Down syndrome produced a more even response pattern across the three options that could indicate random guessing. However, they did offer a higher frequency of responses based on the more developmentally advanced rule II than the other groups. This may be a result of the relatively high CA of participating children with Down syndrome (and thus their greater experience of illness) which may have led to a greater number of participants in this group understanding the probabilistic nature of illness causation. However a note of caution must be made. Perhaps it is possible that the children with Down syndrome may have interpreted the 'maybe' option in a manner differently from the other groups. Specifically, research has shown that children with Down syndrome often use avoidant learning strategies (Wishart, 1996a) and the 'maybe' option may have led these children to be reluctant to commit to a 'yes' or 'no' response. Thus these results may not show greater understanding but more a style of responding to the task by this group. A larger sample size and a more in-depth task such as the one used by Kalish (1998) should be used to investigate this issue further.

#### **4.4.1. Conclusions**

Taking the findings of the present study together clear task differences and some group differences have been identified. This research confirms the recurrent finding that children with autism have a deficit in intuitive psychology, but extends past research in showing that performance of these children in intuitive physics especially, but also biology, is relatively unimpaired compared to typically developing pre-school children.

The differentiated performance demonstrated by children with autism adds weight to the claim that cognition develops in a domain-specific fashion.

The finding that children with autism can reason about tasks pertaining to the domain of physics has been the topic of much discussion and it has recently been claimed that children on the autistic spectrum have a superior ability to reason about phenomena relating to this domain (Baron-Cohen, 2000a). As a result of this speculation and in part due to the debate regarding the cognitive foundations of the domain of biology (see Carey, 1995) Study 2 will focus on the domains of psychology and physics and no further investigation of biological concepts will be pursued in this thesis.

Baron-Cohen's claims of superior physics reasoning among children on the autistic spectrum was not identifiable in the present study due to the inclusion of a young typically developing comparison group. As a result Studies 2 and 3 will compare children on the autistic spectrum with a CA matched group in order to offer a stronger age comparison for the superiority claims to be given consideration. Additionally, in light of the discussion surrounding the false photo task raised in this chapter, Studies 2 and 3 will employ tasks that will tap purely physical reasoning and consideration will be given to tasks from the educational literature discussed in Chapter 3.

A difficulty raised by the present study is that task structure within and between domains differed considerably. Study 2, reported in the following chapter, will attempt to overcome this problem by comparing intuitive psychological and physical understanding using tasks with two conditions that are similar in structure and differ only in content. In addition, Study 2 will not only focus on understanding among participant groups but it will also investigate which domain participants prefer to use when given a choice of utilising either the domain of psychology or physics.



## CHAPTER 5

### STUDY 2: INTUITIVE PSYCHOLOGY AND PHYSICS IN TYPICALLY DEVELOPING CHILDREN AND CHILDREN ON THE AUTISTIC SPECTRUM <sup>\*2</sup>

#### 5.1. Aims of this Chapter

The results of Study 1 showed that there is a dichotomy in understanding pertaining to intuitive psychology and physics concepts in children with autism. The ability of children with autism to reason about physical phenomena has been reported elsewhere (see Baron-Cohen, 1997) but the finding that they can reason competently about physical phenomena is relatively new. Moreover, it has only recently been claimed that children with autism have superior reasoning abilities with respect to the domain of physics (see Baron-Cohen, 2000a). At present there has only been a very small number of direct comparisons made between the difficulties children on the autistic spectrum have in relating to people and the relative ease with which they interact with physical objects (an exception being Baron-Cohen et al., 2001). In an attempt to rectify this situation the study reported in this chapter investigates both the understanding of intuitive psychology and physics in typically developing children and children with autism. It must be noted that this study is not concerned with the precise cognitive structure of intuitive psychology or intuitive physics. It takes it as given that they are both 'core domains of cognition' that are established very early in typical development (Wellman & Gelman, 1992; Wellman & Inagaki, 1997a; Wellman, Phillips & Rodriguez, 2000).

#### 5.1.1. An Overview of Intuitive Psychology and Physics

As discussed in Chapters 2 and 3, it is widely thought that concepts within the domains of intuitive psychology and physics comprise fundamental implicit (and possibly innate) principles. These principles are often evident in early infancy but also encompass developmentally advanced concepts that emerge in later childhood.

---

<sup>\*2</sup> The data from this study is in press in *Autism: International Journal of Research and Practise* (see Appendix E)

To re-cap from Chapter 2, the domain of psychology is utilised during interactions with others and allows feelings, desires, motivations and intentions to be taken into account when reasoning about human behaviour. Intuitive psychology encompasses basic communication skills present in infancy such as shared attention (Mundy & Crowson, 1997) and the ability to imitate facial expressions (Meltzoff & Moore, 1977). It also includes more advanced concepts present in typical development by the age of four years, such as being able to attribute mental states to oneself and others (Leslie, 1987), having an appreciation that seeing leads to knowing (Pratt & Bryant, 1990) and understanding emotional causality (Harris, Johnson, Hutton, Andrews & Cooke, 1989). As development proceeds, more complex concepts, such as having an appreciation of personality traits, emerge (Heyman & Dweck, 1998).

In contrast, despite many physical concepts having been investigated the literature on intuitive physics is very piecemeal (see Howe, 1998). The study to be reported in this chapter will focus on the fundamental physical concepts identified in Chapter 3, such as the movement and characteristics of objects. Intuitive physics initially makes its appearance in children's knowledge of solid cohesive physical objects and the causal regularities that they exhibit. The 'object concept' has been identified as a core constituent of this domain and involves fundamental knowledge found in infants as young as three-to-four months old (Baillargeon et al., 1985). By extension, the domain of physics involves reasoning about the physical causes of non-agent initiated events. More advanced concepts within this domain include the notion that a cause will produce an effect by transmitting a force or restraint to it, or a set of forces will cause trajectories, accelerations and so on (Wellman & Gelman, 1992). The ability to reason about these more advanced object-related concepts typically becomes apparent between the ages of three-to-four years (Das Gupta & Bryant, 1989; Gelman et al., 1980), alongside concepts such as object size and weight (Smith et al., 1985). More developmentally advanced understanding such as knowing how a balance scale works (Siegler, 1976) and having a theory of motion is thought to be present by the ages of seven-to-twelve years (Kaiser et al., 1986).

Although typically developing children can employ specific reasoning systems in relation to psychological and physical phenomena, a large body of research carried out

on children with autism has shown that they lack an understanding of psychological concepts (see Chapter 2). Moreover, accumulating work shows that they have a relatively intact understanding of physical phenomena (see Chapter 3). However, despite claims regarding superior physics understanding among children on the autistic spectrum (i.e. Baron-Cohen et al., 2001) Study 1 was unable to clarify the picture. As a result more detailed research is needed to provide a highly controlled test of this claim and also give a clearer understanding of the typical development of physical reasoning.

### **5.1.2. The Present Study**

In order to make a direct comparison between the two domains of knowledge in question this study employed three tasks, each with an intuitive psychology and intuitive physics condition. The study examined group differences across conditions in each task for three groups of typically developing children, children with autism and a CA matched group. The CA match group was included to provide a direct comparison group for the children with autism in terms of length of experience of the physical and psychological worlds. The typically developing children comprised three groups: pre-schoolers, seven-year-olds and ten-year-olds in order to provide baseline normative developmental data on the newly developed tasks. These comparison groups were designed to allow a full investigation into claims that children on the autistic spectrum have superior reasoning for physical phenomena.

Three tasks were employed in this study, they required participants to complete a picture sequence, categorise cards and respond to a number of multiple-choice questions. The picture-sequencing task gave participants a fixed choice of two options. It was predicted that children with autism would be more likely to respond with the intuitive physical rather than the psychological option. The categorisation task aimed to observe how children would categorise intuitive psychological and physical phenomena. It was expected that children with autism would choose superficial features to categorise psychological items but physical features to categorise physical items. Performance on the multiple-choice task was expected to show children with autism performing the least well on items involving intuitive psychology. However, they were expected to perform at least similarly or possibly better than their CA match group, pre-schoolers and seven-year-olds on the tasks of intuitive physics. The typically

developing ten-year-old children were expected to perform better than all comparison groups on both the psychological and physical conditions of this task.

## **5.2. Method**

### **5.2.1. Participants**

The 94 participants in this study comprised 17 pre-schoolers; 18 seven-year-olds; and 17 ten-year-olds, 21 children diagnosed with autism according to DSM-IV or ICD-10 criteria, and a group of 21 typically developing children matched to the children with autism according to CA and gender. Informed consent was sought and ethical guidelines were followed (see Appendix A). The typically developing children were recruited from one nursery and one state primary school in Edinburgh. All children with autism were being educated within a language unit in one of four mainstream state schools in Edinburgh. Parents reported the diagnosis of children with autism and confirmatory checks were made with school records. Inspection of these records coupled with the details of performance IQ [PIQ] shown in Table 5.1 suggest that these participants were positioned at the high-functioning end of the autistic spectrum.

The receptive vocabulary [RV] of children with autism was assessed using the BPVS-II (Dunn et al., 1997) to ensure that they had an age equivalent of at least four years, the minimum judged necessary to understand task instructions. In addition, all participants were administered the standard performance sub-test of the United Kingdom edition of the Wechsler Pre-school and Primary Scale of Intelligence [WPPSI-R] (Wechsler, 1990) or the Third United Kingdom edition of the Wechsler Intelligence Scale for Children [WISC-III] (Wechsler, 1992) in order to generate a PIQ score. The sample characteristics are shown in Table 5.1.



Table 5.1: Number [N] of participants, mean CA, mean PIQ scores and associated ranges (years; months) of the diagnostic groups participating in Study 2 and the mean RV score and range (years; months) of the participants with autism

Diagnostic Group	N	Mean CA (range)	Mean PIQ * (range)	Mean RV** (range)
Autism	21	6;3 (5;5 – 10;2)	90 (61 – 119)	6;5 (4;5 – 9;0)
CA match	21	6;3 (5;5 – 10;2)	102 (90 – 130)	
Pre-schoolers	17	4;7 (4;4 – 4;11)	101 (86 – 109)	
Seven-year-olds	18	7;4 (7;1 – 7;11)	108 (95 – 140)	
Ten-year-olds	17	10;3 (10;1 – 10;11)	99 (77 – 112)	

\*WPPSI-R or WISC-III \*\*BPVS-II

### 5.2.2. Materials

#### *Picture-sequencing Task*

This task compared physical and psychological causation via a picture-sequencing method modified from the one used by Baron-Cohen et al. (1986). The task included eight picture sequence trials comprising two conditions: four man made artefacts (e.g. car) and four natural artefacts (e.g. flower). These two categories were chosen to reflect a living versus non-living distinction. The former being more psychologically loaded in contrast to the latter that is more associated with physical attributes (see Appendix B). For each picture-sequence trial participants were presented with the first and last picture of a causal sequence. They were then asked to choose, from two pictures depicting different causal mechanisms, the one that would best explain the sequence of events. One picture depicted a physical causal mechanism and the other depicted psychological causation.

The picture-sequence trials were presented randomly. The standard procedure for each trial involved the experimenter placing the first and last picture of the causal sequence onto a Velcro board leaving a suitable gap for the intermediate picture. Participants were told that 'this is the first picture in the story (the experimenter points to the first picture on the Velcro board) and this is the last picture (the experimenter points to the last picture)'. The two intermediate pictures were placed randomly on the table beside the Velcro board avoiding any positional cues that might lead to a systematic bias in responding. Children were then instructed to 'look at these pictures' (the experimenter points to the two intermediate pictures being careful to avoid any cues that might influence the participants choice) and were asked 'which one will go in the middle to tell the best story?' They were then invited to attach their choice to the Velcro board.

Responses to each condition were scored according to the type of causation chosen on a scale from 0 (all items completed with physical causal pictures) to 4 (all items completed with psychological causal pictures).

### *Categorisation Task*

Employing similar methodology to previous categorisation studies (e.g. Savitsky & Izard, 1970; Weeks & Hobson, 1987) this task comprised a psychological and physical condition. In order to examine the degree to which fundamental features of faces (i.e. emotional expression) and fundamental physical laws (e.g. gravity) are salient for participants, these features were combined with a more superficial feature (that did not relate to core psychological or physical principles) in all tasks.

There were four trials for the psychological condition and four trials for the physical condition. Every trial consisted of eight cards that varied in terms of the combinations of fundamental and superficial features (for examples see Appendix C). The fundamental features in the psychological condition comprised four emotional expressions (i.e. happy or neutral, sad or neutral, angry or neutral and surprised or neutral) (expressions were taken from Howlin, Baron-Cohen & Hadwin, 1999). The fundamental features in the physical condition comprised cards depicting one of four physical laws (i.e. floating or sinking, gravity or no gravity, balance or imbalance and object contact or no contact). In both conditions the superficial features were colour (two colours in each trial). By presenting these combinations of features children could

categorise cards either in terms of fundamental laws (psychology or physics) or superficial features (i.e. colour).

All trials followed a standard procedure. A Velcro board was placed in front of the participant with a piece of white tape running down the middle. Participants were presented with an introductory task comprising eight cards (four cards depicted a circle and four a square). They were asked to notice and remember a way in which the cards differed from each other and were initially asked to sort the cards into two groups and then place the card groups on either side of the Velcro board. In line with Weeks and Hobson (1987) this introductory task was designed to test whether the participants could sort cards while allowing the children, especially those with autism, to assimilate the task procedure. Following this, the participants were administered the experimental task. For each randomly administered trial the cards were placed in front of the children in a random pile. The children were then asked to follow the same procedure demonstrated in the introductory task.

Responses to each condition (psychology and physics) were scored according to how categorisation was completed on a scale from 0 (all trials completed according to superficial features) to 4 (all trials completed according to fundamental features).

### *Multiple-choice Task*

Participants were presented with a workbook comprising 12 questions concerning intuitive physics knowledge and 12 on intuitive psychological knowledge (see Appendix D). Each condition comprised of two classes of phenomena that subsumed two further specific principles (see Table 5.2). In relation to physics, the two phenomena were 'object motion' with three questions asked about gravity (from Kim & Spelke, 1999) and three questions on trajectory (from Kaiser, Proffitt & McCloskey, 1985) and 'how things work' with three questions on mechanics (from Metz, 1985) and three questions on balance (from Siegler, 1976). With regard to psychology, the two phenomena were 'emotion', which included three questions on schematic face recognition and three questions on desire based emotions (from Howlin et al., 1999), and 'belief', comprising three questions on simple perspective taking and three questions on 'seeing leads to knowing' (from Howlin et al., 1999). Each sub-category was designed to investigate increasingly sophisticated levels of understanding in order

to accommodate the range of ability in the participant groups and to avoid possible ceiling effects. For example, the variables considered in the balance scale task were weight, distance and weight combined with distance.

Table 5.2: Classes of phenomena employed in each condition of the multiple-choice task

Condition	Category	Sub-category
Physics	Object motion	Gravity
		Trajectory
	How Things Work	Mechanics
		Balance
Psychology	Emotion	Schematic face recognition
		Desire based emotions
	Belief	Simple perspective taking
		Seeing leads to knowing

The experimenter read out each question from the workbook and subsequently asked the participants to choose from three illustrations the ‘best’ answer. In order to make a response participants were instructed to ‘tick the box under the picture that you think best answers the question’. Psychology and physics questions were randomly presented in a standard sequence to participants. The total number of questions was 24 and correct responses were summed to give a score out of 12 for each condition.

### 5.2.3. Procedure

The picture-sequencing, categorisation and multiple-choice tasks were administered randomly to participants in a quiet room with no single session taking longer than 35 minutes. In accordance with this time constraint RV and PIQ assessments were often split over two sessions. In order to reduce task demands items in all three tasks were designed to be of fixed choice requiring limited verbal instructions. In addition, no verbal response was needed from participants who were required only to produce a behavioural response e.g. the placement of the picture that best answered the question onto a Velcro board. This procedure served a number of purposes: 1) it avoided the children with autism being disadvantaged due to their relatively poor communication skills; 2) it focussed participants attention on the task; and 3) it allowed the experimenter to correctly and clearly identify participants’ answers.



Participants were allowed to complete the tasks at their own pace with the experimenter recording their choices. If a response was not forthcoming the experimenter repeated the question/instructions one more time. Positive feedback was given after every task, e.g. 'that's good, well done'.

### **5.3. Results**

#### **5.3.1. Preliminary Analysis of PIQ**

The relationship between PIQ and task performance of each group was analysed for all tasks. A significant positive relationship between PIQ and task performance was found in children with autism and the ten-year-old children in the physics condition of the multiple-choice task ( $r = .79, p < .001$ ;  $r = .55, p < .05$  respectively). Analysis revealed that PIQ accounted for 62% and 30% of the overall variance in task performance. Additionally, independent group analysis revealed a significant negative correlation between the seven-year-olds' PIQ and their performance on the psychological condition of the multiple-choice task ( $r = -.66, p < .05$ ). It was found that PIQ accounted for 43% of the overall variability in task performance. The relationship between PIQ and task performance on the multiple-choice task made it necessary to include PIQ as a measure of co-variance when analysing performance in both conditions of this task.

#### **5.3.2. Task Analyses**

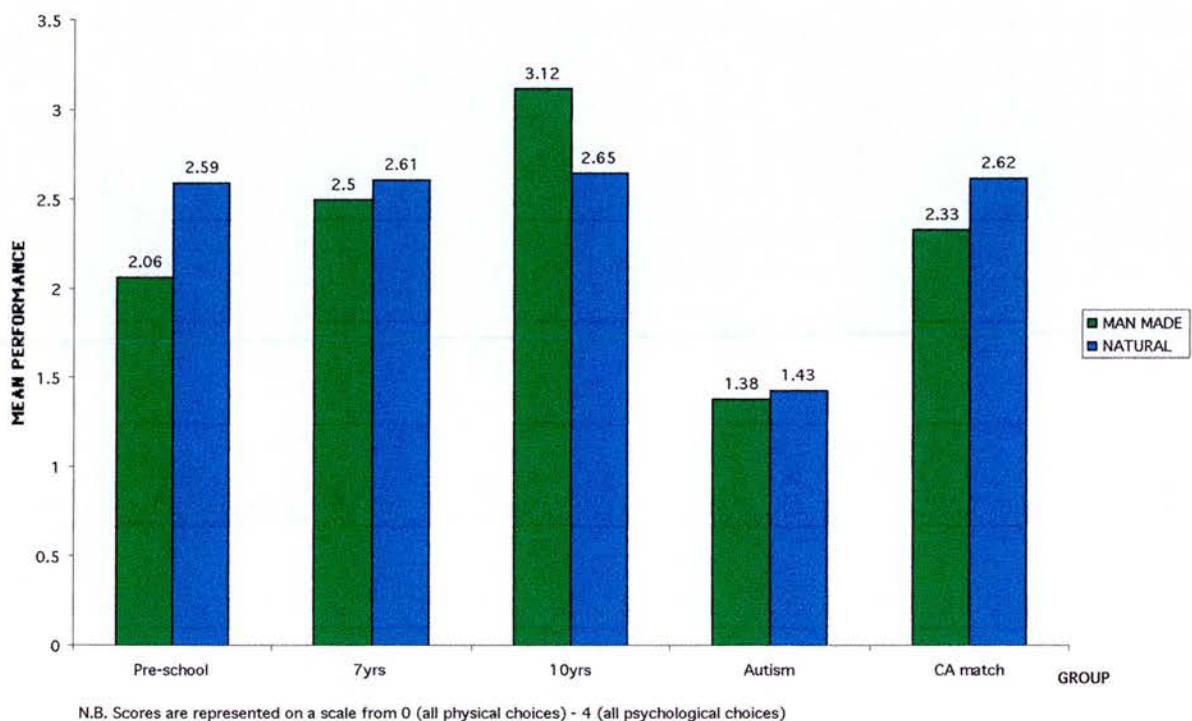
Analysis was carried out on the mean performance scores using one-way related ANOVAs. Analysis of the physics and psychological condition of the multiple-choice task was carried out using an analysis of covariance [ANCOVA] in order to include PIQ as a measure of co-variance. The ANCOVA adjusts the means of the dependant variables (scores on multiple-choice task) to what they would be if all subjects scored equally on the co-variate of PIQ. Controlling for PIQ in this way provides a more conservative and powerful test of differences between the groups (see Tabachnick & Fidell, 1996). For each task post-hoc Bonferroni t-tests with the observed level of significance altered to account for multiple comparisons were carried out. Results are presented separately for each task.

### Picture-sequencing Task

Overall there was a significant positive correlation between the psychological and physical conditions of this task ( $r = .414$ ,  $p < .001$ ).

A one-way ANOVA highlighted significant group differences in the man-made artefact condition ( $F(4, 89) = 6.02$ ,  $p < .001$ ). Post hoc Bonferroni t-tests indicated significant differences between children with autism and the ten-year-olds ( $t(36) = 1.74$ ,  $p < .001$ ). Inspection of the means in Figure 5.1 shows that the children with autism (mean = 1.38) were more likely to choose the physical picture to complete the picture-sequence than the ten-year-olds (mean = 3.15).

Figure 5.1: Mean performance of all five groups on both conditions of the picture-sequencing task



A one-way ANOVA showed significant group differences in the natural artefact condition ( $F(4, 89) = 6.54$ ,  $p < .001$ ). Post hoc Bonferroni t-tests revealed that significant differences lay between the children with autism and the CA match group ( $t(40) = 1.19$ ,

$p < .001$ ) and the ten-year-olds ( $t(36) = 1.22, p < .001$ ). The means illustrated in Figure 5.1 show that children with autism (mean = 1.43) tended to opt more for the physical causal picture to complete the picture sequence than the CA matched group (mean = 2.33) and the ten-year-olds (mean = 2.65), with both groups of typically developing children preferring to complete the sequence with the psychological picture.

### *Categorisation Task*

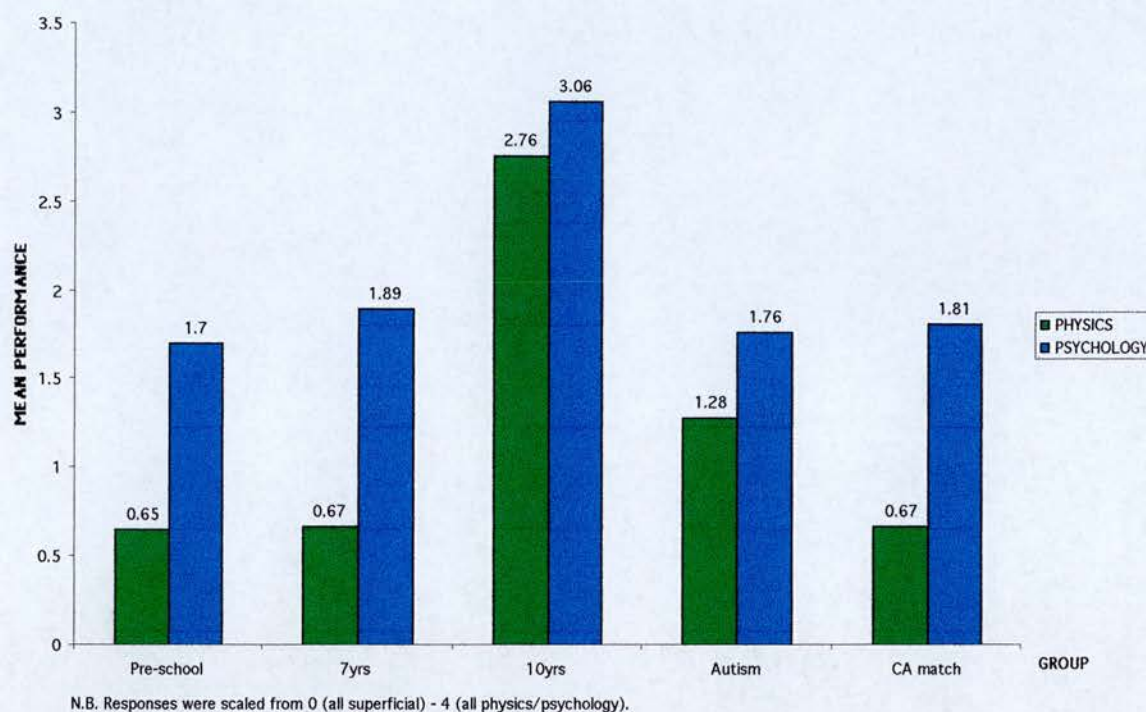
Overall there was a significant positive correlation between performance on the psychological and physical conditions of this task ( $r = .381, p < .001$ ). Further, a significant correlation was identified between performance on the psychological categorisation condition and the psychological condition of multiple-choice task ( $r = .28, p < .01$ ) and between the physics categorisation condition and the physics condition of the multiple-choice task ( $r = .22, p < .01$ ). These results indicate that for each condition (physics and psychology) the categorisation and multiple-choice tasks may be tapping knowledge from the relevant domain.

A one-way ANOVA indicated significant group differences in the physical categorisation condition ( $F(4, 89) = 14.5, p < .001$ ). Post hoc Bonferroni t-tests indicated that there were significant differences between the ten-year-old children (mean = 2.76) and the pre-schoolers (mean = 0.64,  $t(32) = 2.10, p = .001$ ), the seven-year-olds (mean = 0.67,  $t(33) = 2.12, p < .001$ ) and the CA match group (mean = 0.67,  $t(36) = 2.10, p < .001$ ). The ten-year-old children and the children with autism (mean = 1.28) did not significantly differ from each other.

Analysis indicated no significant differences in performance of the five groups in the psychological condition of this task. However, as indicated in Figure 5.2, the ten-year-old group were more likely to categorise according to psychological features than any other group.



Figure 5.2: Mean performance of all five groups on both conditions of the categorisation task



### *Multiple-choice Task*

Preliminary analysis revealed that the physical and the psychological sub-scales within the multiple-choice task both have internal consistency therefore could be analysed separately (Cronbach's Alpha: 0.63 and 0.64 respectively).

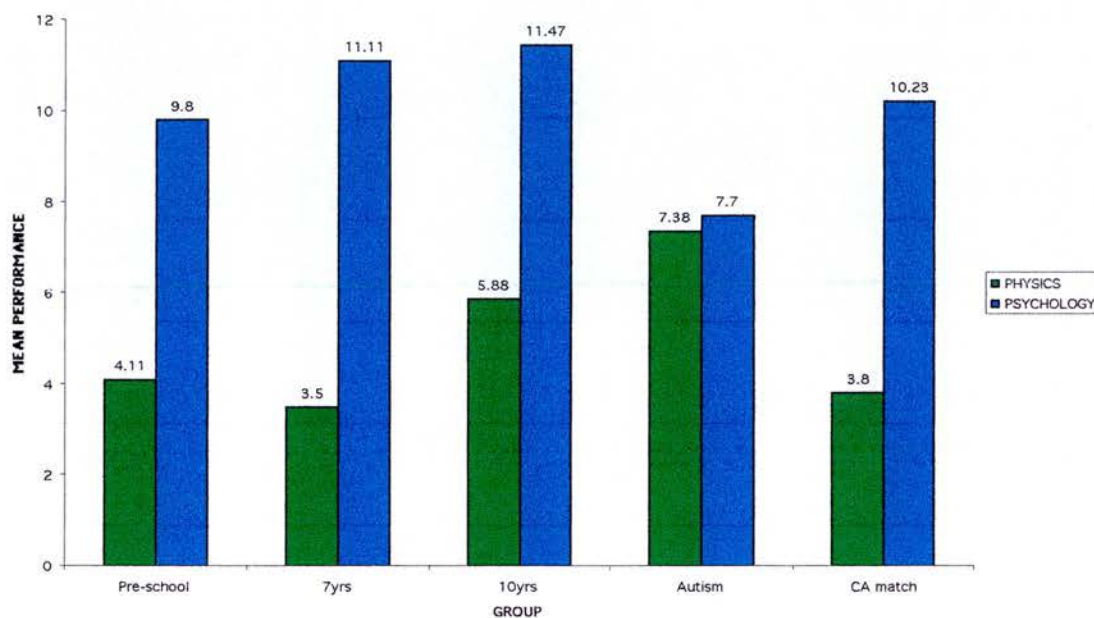
Across all groups a significant negative correlation between performances on the two conditions was identified ( $r = -.21$ ,  $p < .05$ ). However, when this was carried out independently for each group no relationships were revealed.

The ANCOVA results showed a significant regression effect between the co-variant PIQ and task performance on the physical condition ( $F(1, 88) = 11.3$ ,  $p < .001$ ). When this was controlled a significant main effect of group was found ( $F(4, 88) = 17.24$ ,  $p < .001$ ). The adjusted means for the children with autism and the CA matched group were 7.38 and 3.8 respectively. With regard to the pre-schoolers, seven-year-olds and ten-year-



olds the adjusted means were 4.11, 3.5 and 5.88 respectively. Bonferroni t-tests indicated that significant differences lay in task performance between the children with autism and the CA matched group ( $t(40) = 4.3, p = .001$ ); the pre-schoolers ( $t(36) = 3.9, p < .001$ ) and the seven-year-olds ( $t(37) = 5.0, p < .001$ ). Differences were also found between the ten-year-old children and the seven-year-old children ( $t(37) = 2.9, p < .001$ ). The adjusted means illustrated that the children with autism performed significantly better on the physics condition than all groups apart from the ten-year-olds. It was also the case that the ten-year-old children performed significantly better than the CA matched group and seven-year-olds.

Figure 5.3: Adjusted mean performance (maximum score = 12) with PIQ controlled in all five groups on both conditions of the multiple-choice task



As already mentioned PIQ was found to correlate with performance on the psychological condition of the multiple-choice task. However, when analysed using a related ANCOVA with PIQ as a co-variant, no significant effect was found. Using the adjusted means the ANCOVA revealed significant group differences in the psychological condition of this task ( $F(4, 88) = 18.27, p < .001$ ). The adjusted means for

the children with autism and the CA matched group were 7.7 and 10.23 respectively. With regard to the pre-schoolers, seven-year-olds and ten-year-olds the adjusted means were 9.8, 11.11 and 11.47 respectively. Post hoc Bonferroni t-tests indicated that significant differences lay between the children with autism and the four comparison groups: CA match ( $t(40) = 2.59, p = .001$ ); pre-schoolers ( $t(36) = 2.17, p < .001$ ); seven-year-olds ( $t(37) = 3.5, p < .001$ ) and ten-year-olds ( $t(36) = 3.81, p < .001$ ). The means displayed in Figure 5.3 reveal that the children with autism performed significantly more poorly on this condition than the other groups.

#### **5.4. Discussion**

Overall the present study found that children with autism, their CA matched peers, pre-schoolers, seven-year-old children and ten-year-old children demonstrated differentiated performance in all three tasks. The picture-sequencing task showed that when given a choice of two responses, children with autism preferred the physical one. Further, as predicted, the children with autism in this study performed poorly in the multiple-choice condition that tapped intuitive psychological knowledge whereas their performance in the intuitive physics condition was better than that demonstrated by their CA matched peers, pre-schoolers and seven-year-olds. Performance on each task will now be discussed in turn.

The results of the picture-sequencing task showed that in the man-made artefact (i.e. physics) condition children with autism were more likely to opt for the physical picture to complete the causal sequence than the ten-year-old children who preferred to opt for the psychological causal picture. In the natural artefact (i.e. psychological) condition, children with autism were also more likely to choose the physical picture to complete the picture sequence. This was in contrast to the CA matched group and the ten-year-old children who tended to opt for the picture depicting psychological causation. Taken together, these results suggest that children with autism may prefer to reason about causality in a purely physical way employing this domain in relation to both physical and psychological phenomena. It should be noted, however, that the stimuli used may have influenced the findings. The stimuli depicting psychological causation included the common feature of a hand; by contrast, a range of agents represented physical causation. Despite this methodological issue, the results of this task show convincingly

that for children with autism causal cognition in relation to psychology may be guided, at least in part, by intuitive physics.

The results of the categorisation task showed that in the physical condition of the task all groups of children tended to categorised according to superficial features. Likewise, results indicated no differential pattern of response across groups in the psychological categorisation condition with all groups preferring to categorise according to emotional features. This was not as expected since children with autism are well documented as having a difficulty with stimuli of a psychological nature. Previous research had led to the prediction that they would prefer to categorise according to superficial colour features. In addition, previous work has shown that pre-school children typically sort according to superficial features (Gilbert, 1969) and this was not found. Again, these results may have been influenced by the task stimuli. The cards used in this condition were of simple drawn faces that depicted basic emotions and this may have lowered the task demands when compared to studies that use photographs. Furthermore, the task mirrored some of the tasks that children with autism receive in school. For example, they are taught to recognised basic emotions such as happy and sad and observations of work carried out in the language units that the sample was drawn revealed that sorting schematic representations of basic emotions would have been a familiar task for them. Therefore, it may have been better to depict more complex emotions via real photographs in any future extensions of this work.

Performance on both conditions of the multiple-choice task was affected by PIQ. When PIQ was controlled for in the analysis, it was found that children with autism performed more poorly than all other groups (even the pre-schoolers) on the intuitive psychology questions. This supports previous literature charting the difficulty that they have in reasoning about psychological phenomena such as desire and belief. On the physical multiple-choice questions children with autism were shown to have performed significantly better than all other groups apart from the ten-year-old children. The finding that children with autism perform above their CA matched peers and similarly to ten-year-olds who were approximately four years older adds strength to the claim that children with autism have intact and superior knowledge in the domain of physics. The items in this task were adapted from published sources and

worked well with the typically developing children. However, more normative data would be advantageous to further establish their reliability and validity.

It has recently been suggested that ability on intuitive psychology and physics tasks may represent a cognitive trade off with both domains having the same underlying mechanism (see Baron-Cohen et al., 2001). In this study, performance between intuitive psychology and intuitive physics on the multiple-choice task across all groups revealed a significant inverse relationship (i.e. those higher in intuitive psychology tended to be lower in intuitive physics and vice versa). This may be evidence that there is a cognitive trade off between these two reasoning systems. However, when performance was analysed for each group independently no associations between the two conditions were identified. Moreover, positive correlations were found between the psychology and physics conditions in the picture-sequencing and categorisation tasks. According to Baron-Cohen et al. (2001) this may suggest that a single cognitive mechanism (as proposed by domain-general theorists) may represent the two areas of reasoning. Clearly more investigation of the sort reported here is needed with standardised tasks in order to shed light on the underlying cognitive architecture of intuitive psychology and physics.

It has been said that cognition develops from its own foundations (Spelke et al., 1992). Therefore individuals with autism who demonstrate a lack of psychological knowledge and an intact understanding of physical phenomena may have a specific underlying cognitive profile that reflects this. Within the literature many suggestions as to the precise cognitive structure of autistic spectrum disorders have been debated (see Chapter 1). Whatever the case may be, it is clear that children with autism do not effectively reason about psychological phenomena and may compensate by over-applying their knowledge of intuitive physics to all types of phenomena. The results of this study indicate that in children with autistic spectrum disorders there is a coupling of impaired intuitive psychology and intact (and possibly superior) intuitive physics.

#### **5.4.1. Conclusions**

This study supports the recurrent finding of impairment in understanding psychological phenomena among children on the autistic spectrum as well as adding to



the findings of Study 1 that they may have an intact and possibly even superior understanding of intuitive physics (especially in the multiple-choice task). Importantly, the findings suggest that children with autism may prefer to view the world in a physical way including phenomena that would be regarded by typically developing children as pertaining to the domain of psychology.

Based on the findings of Studies 1 and 2 of a potential strength in intuitive physics among children with autism the following study will provide a deeper investigation into the nature of physical knowledge in children on the autistic spectrum in order to give a full account of their understanding in this domain. A key consideration will be to elucidate more clearly whether intuitive physics in children on the autistic spectrum is similar or superior to that of typically developing children. The benefits of in-depth work regarding the precise nature of physical understanding among children on the autistic spectrum may help to shed light on whether or not they have knowledge that can be described as 'theoretical'. It has been argued that they may score highly on multiple-choice tasks asking about physical phenomena without having theoretical understanding (see Gopnik et al., 2000). As a result the concluding study in this thesis, reported in Chapter 6, provides a detailed analysis of the judgements and explanations used by children with Asperger syndrome and a CA and gender matched group of typically developing children in order to investigate this point further.

## CHAPTER 6

### STUDY 3: UNDERSTANDING OF PHYSICAL PHENOMENA IN CHILDREN WITH ASPERGERS SYNDROME: AN INVESTIGATION OF CAUSAL PREDICTIONS AND EXPLANATIONS

#### 6.1. Aims of this Chapter

Studies 1 and 2 found that children with autism display a differentiated level of understanding with regard to psychological and physical phenomena. In general they were shown to perform poorly on tasks of a psychological nature but comparatively well on tasks tapping physical knowledge. The finding that children with autism perform poorly on intuitive psychology tasks has been widely reported (see Baron-Cohen, 2000b). However, there have been very few systematic attempts at investigating the relative strength in understanding physical phenomena among children on the autistic spectrum. For this reason the focus of this study will be solely on intuitive physics.

Like the large majority of research investigating children's domain-specific knowledge, Studies 1 and 2 investigated children's understanding via judgements and predictions. This is not the tradition in the educational literature on physics understanding. In this field of work there is a large volume of research that has examined typically developing children's explanations of a wide variety of physics concepts (e.g. Howe, Rodgers & Tolmie, 1990; Kaiser, Proffitt & McCloskey, 1985; Siegler, 1976). The focus on explanations may be beneficial owing to the fact that verbal utterances have been identified as being particularly revealing of children's understanding (see Hood & Bloom, 1979; Shatz, Wellman & Silber, 1983). In fact, a concern among young children with causes and explanations has been identified as an early contributor to cognitive development (Wellman, Hickling & Schultz, 2000). Thus, the study of children's causal explanations may offer an opportunity to further examine the nature of intuitive physical reasoning in children on the autistic spectrum. However, given the identified difficulties with language in children with autism (see Chapter 1) the study reported

here focussed on individuals with Asperger syndrome in an attempt to investigate both their predictions and explanations offered with respect to a range of physical concepts.

### **6.1.1. Children's Explanations**

Critics of Piaget's clinical interview method have argued that requiring children to articulate explanations is especially demanding and will distort rather than display their understanding (see Bullock et al., 1982). This is perhaps why Piaget found that typically developing children under the age of seven do not have the capacity to explain (Piaget, 1926). However, using more child-focussed methods subsequent work found that children are able to give and understand explanations well before this age (for a review see Donaldson & Elliot, 1990). Consequently, recent researchers claim that investigating children's explanations is both easier and more revealing than traditionally envisaged (Wellman, Hickling & Schultz, 2000). The ability to explain encompasses both linguistic and cognitive demands, namely the ability to understand the phenomena under question and the ability to communicate this understanding, usually by employing the terms 'because' and 'so' (Donaldson & Elliot, 1990). With regard to domain-specific knowledge it has been noted that work on typically developing children's explanations is limited (Wellman, Hickling & Schultz, 2000) and this is also the case for atypically developing children.

Studies from the available literature show that children with autism have difficulties in offering explanations about intuitive psychological concepts. For example, when presented with 'emotion-evoking' stories, high-functioning children with autism gave fewer mental state explanations in relation to typical emotions than both six and ten-year-old typically developing children (Rieffe, Terwogt & Stockmann, 2000). Likewise, Tager-Flusberg and Sullivan (1994) examined the ability of children with autism to explain human action in psychological terms. They found that in contrast to both a typically developing and a non-specific mentally disabled group, the children with autism were less likely to offer mentalistic explanations. This finding was further supported by Happe (1994b) who reported that in comparison to similar CA and MA control groups, children with autism were impaired at providing context appropriate mental state explanations. In addition to showing an impaired performance in offering psychological explanations, Gopnik et al. (2000) have recently examined the explanations used by children with autism to reason about biological phenomena.

Results showed that they offered fewer explanations based on biological processes than a control group of typically developing children (see Chapter 4 for more details). Despite the argument that children on the autistic spectrum can reason effectively about physical phenomena, to date no one has specifically focussed on the explanations they use in relation to phenomena pertaining to the domain of physics thus there is clearly a need for research in this area.

With respect to typically developing children it is well documented that young pre-schoolers extensively bombard adults with 'why' questions about the physical world. As a result they obtain direct linguistically encoded information about the physical world from an early age (Karmiloff-Smith, 1992) and it has been suggested that this may advance the acquisition of physical knowledge (Bartsch & Wellman, 1989; Gopnik & Meltzoff, 1997). However, initial work reported that two-year-old children offer causal explanations that are exclusively psychological in nature and do not talk about causal events that occurred between physical objects in the world (Hood & Bloom, 1979). This finding has been disputed in a recent study of children's explanations examined in a naturalistic setting by Wellman, Hickling and Schultz (2000). They found that from two years of age, children could comment on a variety of topics using explanations from the physical domain of reasoning. For example, when asked to reason about a character's behaviour over a variety of topics they produced statements that appealed to or implied physical forces such as gravity or the wind. Furthermore, it has recently been found that not only can young children express physical causal explanations but they can also distinguish them from psychological ones (Hickling & Wellman, 2001).

Outside these handful of observations very little work has focussed on children's explanations of physical and other phenomena and, within the domain-specific literature, there is a strong methodological focus on judgement and prediction tasks (see Wellman, Hickling & Schultz, 2000). In contrast, the educational literature contains many studies that have focused on explanations that children offer in relation to physical phenomena. These studies have been particularly interested in the way in which children's explanations focus on the variables inherent in the phenomena under question. It is thought that children's theories may constrain the variables selected (see Howe, 1998). This work has found that children's explanations can be particularly



revealing with regard to their level of understanding. For example, as mentioned in Chapter 3, Siegler (1976) investigated the judgements and explanations offered with regard to a balance scale. His results indicted that children's explanations could be categorised into four rules. Likewise, studies have focussed on the explanations offered by children with regard to whether an object will float or sink (i.e. Bidduph, 1983; Howe et al., 1990; Stephans, Beiswerger & Dyche, 1986). As a result of analysing children's causal explanations these studies have identified a number of levels of understanding across children of different ages that progress developmentally (see Chapter 3 for details). Such patterns of development could not have been uncovered had it not been for the methodological focus on explanations as opposed to judgement tasks thus it appears to be the case that explanations may provide a worthwhile methodological route into assessing children's domain-specific understanding.

### **6.1.2. The Investigation of Theoretical Knowledge**

Within the domain-specific literature the lack of work on children's explanations is surprising because many have described this understanding as 'theoretical', thereby emphasising its capacity for explanatory knowledge. What constitutes a theory is as yet an unresolved issue (see Chapter 1). However, theories are commonly deemed responsible for allowing the reasoner to identify phenomena and engage the appropriate causal explanatory framework in order for reasoning to take place (Wellman, 1990; Wellman & Gelman, 1992). As a result, intuitive theories have been described as providing causal understanding of the real world (Johnston & Carey, 1998) and are utilised in order to predict, interpret and explain (Gopnik & Meltzoff, 1997). Taking these definitions on board it seems sensible to conclude that analysing children's explanations may yield a fruitful avenue of investigation into the theoretical nature of physics knowledge. In keeping with this viewpoint, Gopnik et al. (2000) have recently claimed that the theoretical understanding of biology may be best assessed through analysis of explanations in addition to accuracy of predictions about, for example, categories of living/non-living things. They state that "explanatory accounts may yield insights into the processes through which theoretical understandings are tested and revised" (Gopnik et al., 2000; p68). Accordingly they have concluded that the inability of children with high-functioning autism to give appropriate explanations regarding the classification of stimuli into non-living and living exemplars highlights their lack of theoretical understanding in the domain of biology.

Using explanations alone as a window into children's theoretical knowledge may be unwarranted. Pine and Messer (2000) suggest that a 'theory' allows children to go beyond basic observations and serves as an explanatory system. They suggest that children's theories may be best observed via non-verbal implicit tasks (i.e. judgements and predictions) and verbally explicit tasks (i.e. explanations). As discussed in Chapter 1, in contrast to explicit knowledge, implicit knowledge cannot be adequately verbalised and is often viewed as piecemeal, simpler knowledge that is more perceptually grounded (see Keil, 1999). Many consider implicit non-verbalised understanding as non-theoretical (e.g. Karmiloff-Smith, 1992). This assertion stems from the assumption that if children cannot express a belief then they could not have such a belief. As a result, the inability of children to express explanations about a wide range of phenomena has been taken as evidence of a lack of understanding in the areas under scrutiny (Keil, 1999). However, there is a wide volume of work based on children's judgements and predictions which claims that young children have domain-specific theories from an early age (see Wellman & Gelman, 1992). In light of this debate the investigation of both children's judgements and explanations may provide a useful combination to further investigate their understanding of intuitive physics. By its very nature implicit knowledge may be used when offering both predictions and explanations however, the knowledge utilised when giving explanations can only be explicit. However, before this methodological consideration will advance the field of domain-specificity a more detailed examination of explanations from a domain-specific perspective is needed. This is especially the case with regards to the understanding of intuitive physics in both typically developing and atypically developing children.

### **6.1.3. The Present Study**

The present study aimed to further investigate intuitive physics knowledge among children on the autistic spectrum. Participants comprised children with Asperger syndrome and group matched according to CA and gender. As shown in Chapter 1, current diagnostic criteria recognise Asperger syndrome as similar to autism in terms of marked impairments in social skills, but note the difference as being the absence of any language or cognitive delay (APA, 1994; WHO, 1993). However, despite having relatively intact language and cognitive abilities, children with Asperger syndrome have still been found to display a differentiated level of performance between the domains of psychology and physics whereby superiority in physical understanding is

evident (Baron-Cohen et al., 2001). Thus the focus on this group allows the examination of this strength by examining their explanations of physical phenomena in a relatively pure form without the presence of other cognitive factors that may influence the findings (such as poor language skills). It must be noted that although this thesis conceptualises high-functioning autism and Asperger syndrome as similar variants on the autistic spectrum (see Chapter 1) it was necessary, in order to compare findings of the present study with that of Baron-Cohen et al.'s (2001), that this study only included participants with a clinical diagnosis of Asperger syndrome.

Due to the current lack of research regarding the methodological use of explanations this study examined group differences in predictions and explanations offered with respect to four physical concepts. In an attempt to integrate research from the educational literature, and in keeping with the three main strands of intuitive physics identified in Chapter 3, this study employed four tasks comprising the concepts of floating/sinking, balance, projectile motion and vertical movement. In order to reason effectively about these four concepts, knowledge of more than one physical variable is required thus a full understanding of these concepts may not therefore be present until the age of 12 years (see Howe, 1998). The use of these concepts allowed participants to provide an explanation based on a single variable or a combination of two variables thus identifying an increasingly sophisticated range of understandings. For the purpose of this study, a high level understanding of floating/sinking must comprise knowledge about the size and weight of the object under scrutiny. A high level understanding of the workings of a balance scale must integrate knowledge of weight and distance. A high understanding of projectile motion must comprise knowledge of velocity and air resistance, and a high understanding of vertical movement must comprise knowledge of friction and mass. Additionally, since PIQ was related to performance on the multiple-choice task employed in Study 2, and also to ensure that both groups have comparable verbal IQ scores, an IQ score for each child was generated.

It was hypothesised that if children with Asperger syndrome have an intact domain of physics then their predictions and explanations given with respect to the four physical concepts tested in this study would not differ from a CA matched group. However, if children with Asperger syndrome have a precocious domain of physics (as suggested by Baron-Cohen, 2000a) then it would be expected that they would exhibit a greater

number of correct predictions than a CA matched group. In addition their explanations would be indicative of a greater level of understanding than their CA matched peers and a more appropriate identification of the salient variables implicated in each task would be evident.

## 6.2. Method

### 6.2.1. Participants

The participants were 20 children from six mainstream schools covering a wide range of socio-economic catchment areas in Edinburgh and the Lothians. Informed consent was sought and ethical guidelines were followed (see Appendix A). Participants comprised two groups: 10 children diagnosed with Asperger syndrome according to DSM IV or ICD-10 criteria and 10 typically developing children matched according to CA and gender. Parents reported the diagnosis of the children with Asperger syndrome and confirmatory checks were made with school records. Research with children on the autistic spectrum is abundant in Edinburgh and the surrounding districts. This coupled with an inclusion criteria of only those children with a clinical diagnosis of Asperger syndrome resulted in difficulty recruiting participants and is reflected in the small sample size. All participants were administered the Weschler Abbreviated Scale of Intelligence (Weschler, 2000) in order to yield an IQ score as well as a Verbal IQ [VIQ] and a PIQ score. The sample characteristics are detailed in Table 6.1.

Table 6.1: Number [N] of participants, mean CA (years; months), mean IQ, PIQ and VIQ scores and associated ranges of each group participating in Study 3

Diagnostic Group	N	Mean CA (range)	IQ* (range)	PIQ* (range)	VIQ* (range)
Asperger Syndrome [AS]	10	9;0 (7;1-11;3)	100.4 (85-115)	100 (86-112)	99.6 (87-121)
CA Match Group [CA]	10	9;1 (7;1-11;3)	104.1 (89-112)	99.6 (86-122)	105.8 (89-112)

\*WASI



### 6.2.2. Materials and Coding Schemes

Four tasks pertaining to the physical concepts of floating/sinking, balance, trajectory and vertical movement were employed. With exception of the vertical movement task, design was based on previous literature reviewed in Chapter 3.

Procedures were similar across all tasks and required that children offer a prediction about the phenomenon under investigation (e.g. will this item float or sink?) followed by an explanation to support their prediction. Subsequently, participants were required to interact behaviourally with the test materials in order to observe the phenomenon in question and declare if their prediction was accurate. This stage was included to engage children's attention and motivate them in the testing situation. All tasks conformed to the sequence: predict, explain and observe.

#### *Floating/Sinking Task*

Participants were presented with a clear tank of water and eight objects/exemplars embodying four variables. The variables (and objects) chosen were size (large ball and small ball), weight (sponge and rock), having air inside or not (empty bottle and full bottle) and flatness (flat piece of plastic and flat piece of metal). Previous work has shown that children commonly identify these four variables as being relevant to whether an item floats or sinks (see Biddulph, 1983; Laurendeau & Pinard, 1962). For each exemplar participants were required to make their predictions with respect to whether the object would float/sink before being allowed to touch the objects under investigation. Howe (1998) states that 'kinesthetic awareness' is not the same as having an understanding of salient variables. Objects were presented individually in a random sequence. Participants were asked:

Predict: 'Do you think this object will float or sink?'

Explain: 'Why do you think that?'

Observe: 'Put the object in the tank of water'.

For each exemplar participants were categorised as either right or wrong according to whether they were correct in their prediction about the bouancy of the object under scrutiny. For all exemplars the explanations offered by participants were categorised according to four descriptive levels identified by Biddulph (1983) and Howe et al.

(1990). Additionally a level allowing for children not knowing was included (inter-rater reliability = 0.93). The five levels representing increasingly sophisticated understanding were defined as: 1) *don't know*; 2) *irrelevant/wrong object properties*, involving incorrect references to properties such as the shape, orientation, surface feature and constitution of the object; 3) *relevant object properties*, involving correct references to properties such as size and weight; 4) *liquid properties*, involving references to the property of the water; and 5) *relative density* involving reference to the property of the water in relation to the object.

### **Balance Task**

Participants were randomly presented with eight different balance scale problems comprising one of three variables found by previous research to be relevant to children's thinking about a balance scale (e.g. Siegler, 1976; see Chapter 3). Two trials made reference to the variable *weight*, two comprised reference to the variable *distance* and four comprised reference to *weight and distance*. The *weight* variable involved presenting children with equal or unequal weights on each arm. The *distance* variable involved equal number of weights on each arm that were placed at differing distances from the fulcrum. The *weight and distance* variable involved two problems, conflict-weight and conflict-balance. Both cases involved unequal weights on each arm; the conflict-weight problems involved the balance tipping to the side with the most number of weights and the conflict-balance problem involved the balance scale balancing. For each problem participants were initially presented with the 'balance problem' on a 2D paper version of the balance scale and were asked:

Predict: 'Do you think putting the pegs like this (experimenter places the pegs onto the 2D paper balance) will make that balance scale (experimenter points to balance scale) balance?'

Explain: 'Why do you think that?'

Observe: 'Place the pegs on the balance scale in the same way'.

For each exemplar participants were categorised as either right or wrong according to whether they were correct in their prediction about whether the balance scale would or would not balance. For all exemplars the explanations offered by participants were categorised according to three descriptive levels found by Siegler (1976). In addition a

level allowing for children not knowing was included (inter-rater reliability = 0.96). The four levels representing increasingly sophisticated understanding were defined as: 1) *don't know*; 2) *weight*, whereby explanations were based only on the number of pegs on each side of the fulcrum; 3) *distance*, whereby explanations were based only on the distance the pegs were from the fulcrum; and 4) *weight and distance*, whereby explanations were based on the weight on each arm and the distance the pegs were from the fulcrum.

### *Trajectory Task*

Participants were presented with eight exemplars of a situation whereby the movement of a ball could be described as occurring. Exemplars were presented in a random sequence and comprised of two variables: *carried* and *rolled* (see Kaiser, Proffitt & McCloskey, 1985). The *carried* variable depicted exemplars of a ball being carried by something that was moving (e.g. a helicopter, an aeroplane, a man running and a man on a bike). The *rolled* variable depicted exemplars of a ball rolling from a stationary object (e.g. a hill, a table, a box and from a curvilinear tube). Exemplars were presented randomly on individual sheets of A4 paper and participants were instructed to complete the 2D pictures by drawing the path that the ball would take from starting to fall/roll until hitting the ground. For feedback the correct path of the ball for each exemplar was depicted on an A4 sheet of acetate in red ink. For each exemplar participants were asked:

Predict: 'Where do you think the ball will land when it is dropped from the X/when it rolls off the X? Using the pencil, draw the path the ball will take when it starts to drop/roll until it hits the ground'.

Explain: 'Why do you think that?'

Observe: 'Now I'm going to show you the correct path of the ball (experimenter covers the child's A4 sheet of paper with the acetate of the correct path)'.

Initially for each exemplar participants were categorised as either right or wrong according to whether they were correct in their prediction about the path of the ball. In line with Kaiser, Proffitt and McCloskey (1985) to be granted with a correct response children's drawings had to indicate a parabolic curve i.e. the ball begins to fall forward and downwards as soon as it leaves the supported surface. To investigate responses to

this task in more depth, children's predictions were also categorised according to three descriptive levels of reasoning found by Kaiser, Proffitt and McCloskey (1985). In addition a level allowing for incorrect responding was included (inter-rater reliability = 0.92). The four levels represented increasingly sophisticated understanding and were defined as: 1) *incorrect*; 2) *straight down*, whereby the ball is depicted as falling straight down; 3) *inverted L-shape*, where the ball is depicted as continuing horizontally for some distance before falling straight down; and 4) *parabolic*, where ball is depicted as falling forward and downwards as soon as it leaves the supported surface. For all exemplars the explanations offered by participants were also categorised according to these four levels of analysis.

### ***Vertical Movement Task***

Participants were presented with eight trials of a toy wooden truck moving down a wooden ramp. These were presented in a random sequence and each comprised a combination of two variables, namely *weight* of the truck and *ramp surface*. The exemplars of *weight* comprised two conditions (e.g. with and without marbles in the truck) and *ramp surface* comprised four conditions inducing varying degrees of friction (e.g. carpet, bubble wrap, sandpaper and shiny card). Before the experimenter allowed the truck to move down the ramp, participants were instructed to draw a line across a sheet of paper (present at the bottom of the ramp) where they thought the truck would stop. For each exemplar participants were asked:

Predict: 'Draw a line on the paper where you think the truck will stop'.

Explain: 'Why do you think that?'

Observe: 'Look at the truck rolling down the ramp'.

For each exemplar participants were categorised as either right or wrong. To be granted with a correct prediction the toy truck had to be over the line drawn by participants. For all exemplars the explanations offered by participants were categorised according to four descriptive levels, three of which were based on the salient variables under observation. Additionally a level allowing for children not knowing was included (inter-rater reliability = 0.98). The four levels represented increasingly sophisticated understanding and were defined as: 1) *don't know*; 2) *surface*, where reference was only made to the surface material on the ramp; 3) *weight*, where reference was made only to



the weight of the truck; and 4) *surface and weight*, where reference was made to both the surface material of the ramp and the weight of the truck.

### 6.2.3. Procedure

Participants were administered the IQ test in a single session lasting approximately 30 minutes. One week later the experimental tasks were conducted. Participants were tested individually in a quiet setting. Tasks were administered randomly and were presented in a single session typically lasting between 40 and 50 minutes. Between tasks participants were asked if they would like to take a break however, this rarely occurred and on the whole participants were highly motivated with the task material. All sessions were video-recorded.

### 6.3. Results

Data was analysed using non-parametric statistics since it was not normally distributed and because of the small sample size. Analysis of the co-variants was considered first using non-parametric Spearman's Rho correlations. For each significant result the correlation co-efficient was squared in order to measure the amount of variability in one variable that is explained by the other. Since data did not fit parametric assumptions these confounding variables could not be controlled in subsequent analysis.

Predictions: For each task a descriptive account of the predictions offered by both groups of children is provided first. Following this the number of correct predictions in each task given overall by each participant (out of eight) was compared between groups using a non-parametric Mann-Whitney U-test for unrelated samples. Each variable (e.g. size, weight, air inside, flatness) in every task (e.g. floating/sinking) was also analysed independently by summing scores for trials tapping each variable. Between group analysis was carried out using Mann-Whitney U-tests.

Explanations: For each task (e.g. balance) a descriptive account of the explanations offered by both groups of children is provided first. Subsequently the explanations offered by participants were analysed across variables (e.g. weight, distance, conflict/weight, conflict/balance). Analysis of each variable independently was not justified because of the small number of explanations that would have represented each

level. For each task, analysis of explanations as a function of level required participants to be given a score indicating a level of correctness regarding their explanations across the eight exemplars. With regards to the floating/sinking task each participant was given a score between 8 (i.e. all eight exemplars were answered according to Level 1) and 40 (i.e. all eight exemplars were answered according to Level 5). For the balance, trajectory and vertical movement tasks each participant was given a score between 8 (i.e. all eight exemplars answered according to Level 1) and 32 (i.e. all eight exemplars answered according to Level 4). For each task group differences were investigated using a Mann-Whitney U-test.

### **6.3.1 Analysis of Co-variants**

The relationship between participant's IQ, VIQ and PIQ scores and task performance was analysed overall and for each task individually. A significant positive relationship was found between PIQ and task performance of the children with Asperger syndrome on the trajectory task ( $r = 0.67, p < .05$ ). Analysis revealed that PIQ accounted for 44% of the overall variability in the task performance. A significant positive relationship was found between PIQ and task performance of the CA matched group over all four tasks ( $r = 0.70, p < .05$ ) and on the floating/sinking task ( $r = 0.70, p < .05$ ). It was found that PIQ accounted for 49% of the overall variability across all four tasks and 49% of the overall variability in the floating/sinking task.

Analysis of age and task performance revealed a significant positive relationship between age and overall task performance across both groups ( $r = 0.42, p < .05$ ). Age accounted for 18% of the variation in task performance. Additionally a significant positive relationship was found between age and performance of the CA matched group on the trajectory task ( $r = 0.66, p < .05$ ). With regard to the CA matched group age was shown to account for 44% of the variability in performance on the trajectory task.

### **6.3.2. Analysis of Tasks**

#### *Floating/Sinking Task*

As shown in Table 6.2 the most correct predictions were made with regard to the *weight* variable where eight children with Asperger syndrome and seven typically developing children predicted the correct outcome to both exemplars.

A Mann-Whitney U-test revealed no significant group difference in the number of correct predictions given by each group across the eight exemplars in the floating/sinking task. Each variable was investigated independently whereby participants were given a score of 0 (both exemplars incorrect), 1 (one exemplar correct) or 2 (two exemplars correct). For each variable a Mann-Whitney U-test revealed no significant group differences.

Table 6.2: Number of participants predicting both exemplars incorrectly [0] and number predicting one [1] and two [2] exemplars correctly for each variable in the floating/sinking task

Group	Size			Weight			Air Inside			Flatness		
	0	1	2	0	1	2	0	1	2	0	1	2
AS N=10	2	5	3	1	1	8	1	5	4	2	5	3
CA N=10	0	9	1	1	2	7	0	7	3	1	4	5

Table 6.3 shows the number of explanations given as a function of level across the eight exemplars. The children with Asperger syndrome offered more Level 1 responses than the CA match group (on 17 and 1 occasion respectively). Overall the CA matched group tended to only offer Level 2 and 3 explanations (on 49 and 30 occasions respectively). At Level 2, the level of irrelevant or wrong object properties, there were irrelevant references to size (e.g. 'small objects float') and weight (e.g. 'heavy things float') as well as references to wrong object properties (e.g. 'it floats because it's shiny and has sharp edges'). Level 3 encompassed references to relevant object properties and thus there was less scope for variability in answers. Across all 20 children, four relevant object properties were offered for floating (light, small, spread out, having air inside) and three were offered for sinking (heavy, big, hard). Level 4 explanations required reference to liquid properties and were offered in reference to three objects by one child with Asperger syndrome. He stated that objects would sink (float) if they were heavier (lighter) than the water. None of the children in this study elicited an explanation based on relative density (i.e. Level 5).

In order to analyse explanations across the floating/sinking task each participant was scored according to the level of explanation offered for each exemplar (i.e. sum scores ranged from 8 to 40). This data was analysed using a Mann-Whitney U-test which revealed significant group differences ( $U=14$ ,  $n= 20$ ,  $p < .05$ ) whereby the CA matched group (mean rank = 14.1) were found to offer more advanced explanations than the children with Asperger syndrome (mean rank = 6.9).

Table 6.3: Number of explanations provided as a function of level across all 8 exemplars in the floating/sinking task

Group	Level 1 Don't Know	Level 2 Irrelevant/ Wrong Object Properties	Level 3 Relevant Object Properties	Level 4 Liquid Properties	Level 5 Relative Density	Total Explanations (8 per child)
AS N=10	17	36	24	3	0	80
CA N=10	1	49	30	0	0	80

### **Balance Task**

With regards to the balance task most correct predictions were found with regard to the *weight* variable where eight children with Asperger syndrome and all ten typically developing children predicted the correct outcome to both problems (see Table 6.4). Both groups had difficulty with the *conflict/balance* problems. However, overall the children with Asperger syndrome performed better on these exemplars with four children answering one problem correctly, compared with two of their CA matched peers, and three children answering both problems correctly.

A Mann-Whitney U-test revealed no significant group difference in the number of correct predictions given across the eight exemplars. In order to analyse variables independently each participant was given a score of 0 (both exemplars incorrect), 1 (one exemplar correct) or 2 (two exemplars correct) for each variable. Four Mann-Whitney U-tests were carried out and a significant group difference was found in the *conflict-balance* variable ( $U = 22$ ,  $n = 20$ ,  $p < .05$ ) whereby children with Asperger syndrome



(mean rank = 13.3) offered more correct predictions than their CA matched peers (mean rank = 7.7).

Table 6.4: Number of participants predicting both exemplars incorrectly [0] and number predicting one [1] and two [2] exemplars correctly for each variable in the balance task

Group	Weight			Distance			Conflict/ Weight			Conflict/Balance		
	0	1	2	0	1	2	0	1	2	0	1	2
AS N=10	0	2	8	2	5	3	1	4	5	3	4	3
CA N=10	0	0	10	3	4	3	0	1	9	8	2	0

Table 6.5 shows the number of explanations given as a function of level across the eight exemplars. Children with Asperger syndrome produced Level 1 responses on more occasions than their CA peers. Both groups of children produced Level 2 explanations most frequently; the children with Asperger syndrome produced a total of 47 and the CA match group offered 57. Level 3 explanations required children to refer to the *distance* each peg was from the fulcrum and was offered as a means of explanation on three occasions by both groups. The most advanced level (Level 4) required a reference to both *weight and distance* and children with Asperger syndrome offered these explanations less (11 occasions) than their CA matched peers (19 occasions).

In order to analyse explanations across the balance task each participant was scored according to the level of explanation offered for each exemplar (i.e. scores ranged from 8 to 32). A Mann-Whitney U-test revealed significant group differences ( $U = 21$ ,  $n = 20$ ,  $p < .05$ ) whereby the CA matched group (mean rank = 13.4) offered more advanced explanations than the children with Asperger syndrome (mean rank = 7.6).

Table 6.5: Number of explanations provided as a function of level across all 8 exemplars in the balance task

Group	Level 1 Don't Know	Level 2 Weight	Level 3 Distance	Level 4 Weight & Distance	Total Explanations (8 per child)
AS N=10	19	47	3	11	80
CA N=10	1	57	3	19	80

### *Trajectory Task*

As shown in Table 6.6, with respect to the *carried* variable, one child with Asperger syndrome and two CA matched children correctly predicted the outcome of all four exemplars in the trajectory task. In contrast no children correctly predicted the outcome of all four exemplars in the *rolled* variable.

A Mann-Whitney U-test revealed no significant group difference in the number of correct predictions given across the eight exemplars in the trajectory task. In order to analyse predictions given for each variable independently participants were given a score of 0 (all four exemplars incorrect), 1 (one exemplar correct), 2 (two exemplars correct), 3 (three exemplars correct) or 4 (four exemplars correct) for each variable. Two Mann-Whitney U-tests were employed and results indicated a significant group difference in the *rolled* variable ( $U = 22$ ,  $n = 20$ ,  $p < .05$ ) whereby the CA matched peers (mean rank = 13.05) offered more correct predictions than the children with Asperger syndrome (mean rank = 7.9).

Table 6.6: Number of participants predicting four exemplars incorrectly [0] and number predicting one [1], two [2], three [3] and four [4] exemplars correctly for each variable in the trajectory task

Group	Carried					Rolled				
	0	1	2	3	4	0	1	2	3	4
AS N=10	1	0	4	4	1	0	3	5	2	0
CA N=10	0	2	3	3	2	0	1	2	7	0

To investigate predictions in more depth they were coded according to four levels: 1) incorrect; 2) straight down; 3) inverted L-shape; and 4) parabolic. As shown in Table 6.7, in comparison to the CA matched group the children with Asperger syndrome were overall less likely to predict an incorrect trajectory (21 and 29 occasions respectively). Furthermore, children with Asperger syndrome were more likely to be incorrect with regard to the *rolled* variable (14 occasions) than the *carried* variable (7 occasions) whereas the CA matched group offered wrong predictions similarly for both variables (14 and 15 occasions respectively). Children with Asperger syndrome were more likely to offer a straight down prediction with regard to exemplars from the *carried* variable (10 occasions) than the *rolled* variable (4 occasions). Across both groups children offered straight down predictions with similar frequency. The CA match group were more likely to offer inverted L-shaped predictions in respect to the *carried* variable (6 occasions) unlike the children with Asperger syndrome who offered this type of prediction in a similar fashion across both variables (on 8 occasions each). Both groups of children made frequent predictions of a parabolic curve in both variables. In order to analyse this data inferentially participants were given a score based on the level of correctness awarded to each prediction (i.e. scores ranges from 8 to 32). Three Mann-Whitney U-tests were employed (i.e. for each variable and overall). Results revealed no significant group differences in the level of prediction offered.

Table 6.7: Number of predictions given as a function of level across all 8 exemplars in the trajectory task

Variable	AS				CA			
	Level1	Level 2	Level 3	Level 4	Level 1	Level 2	Level 3	Level 4
	I	SD	IL	P	I	SD	IL	P
Carried	7	10	8	15	14	9	6	11
Rolled	14	4	8	14	15	9	1	15
Overall	21	14	16	29	29	18	7	26

Key: I = Incorrect; SD = Straight down; IL = Inverted L-shape; P = Parabolic

Table 6.8 shows the number of explanations given as a function of level across the eight exemplars. Level 1, representing incorrect responses, was offered more frequently by the CA match group than the children with Asperger syndrome (45 and 33 occasions respectively). Level 2 explanations incorporating a reference to the ball falling straight down were given a comparable number of times by the children with Asperger syndrome (35 occasions) and the CA matched group (34 occasions). Although participants in both groups predicted that the path of the ball would follow an inverted L-shape path (see Table 6.7) no explanations were given that offered such a reference (i.e. Level 3). Children with Asperger syndrome offered Level 4 explanations based on a parabolic path on 11 more occasions than their CA matched peers. In order to analyse explanations as a function of level each participant was given a score between 8 and 32. A Mann-Whitney U-test revealed no significant differences in the level of explanations offered by each group.

Table 6.8: Number of explanations provided as a function of level across all 8 exemplars in the trajectory task

<b>Group</b>	<b>Level 1 Incorrect</b>	<b>Level 2 Straight Down</b>	<b>Level 3 Inverted L- shape</b>	<b>Level 4 Parabolic</b>	<b>Total Explanations (8 per child)</b>
AS N=10	33	35	0	12	80
CA N=10	45	34	0	1	80

### *Vertical Movement Task*

Overall the children performed poorly in the vertical movement task. Table 6.9 shows the number of participants predicting all four exemplars incorrectly and the number predicting one, two, three and four exemplars correctly. These response patterns show that within the *weight* variable one child with Asperger syndrome correctly predicted the outcome of all four exemplars. With regard to the *surface* variable, no children correctly predicted the outcome of all four exemplars. A Mann-Whitney U-test revealed no significant group difference in the number of correct responses given across the eight exemplars in the vertical movement task.



In order to analyse response patterns each participant was scored as either 0 (all four exemplars incorrect), 1 (one exemplar correct), 2 (two exemplars correct), 3 (three exemplars correct) or 4 (four exemplars correct) for each variable. Two Mann-Whitney U-tests revealed no significant group differences in the way participants responded to each variable.

Table 6.9: Number of participants predicting four exemplars incorrectly [0] and number predicting one [1], two [2], three [3] and four [4] exemplars correctly for each variable in the vertical movement task

Group	Weight					Surface				
	0	1	2	3	4	0	1	2	3	4
AS N=10	1	3	5	0	1	1	2	4	3	0
CA N=10	0	3	4	3	0	1	5	3	1	0

Table 6.10 shows the number of explanations given as a function of level across the eight exemplars. Children with Asperger syndrome produced Level 1 responses with more frequency than their CA matched peers (on 23 and 15 occasions respectively). Level 2 explanations were awarded if a child only referred to the *surface of the ramp* to explain the movement of the truck. This type of explanation was given most frequently by both groups of children: 40 times by the children with Asperger syndrome and 38 times by the CA matched group. Level 3 explanations required children to refer to the *weight* of the truck to explain movement and were offered as a means of explanation 11 times by the children with Asperger syndrome and eight times by the CA matched group. The most advanced level of explanation (Level 4) based on reference to both the *surface of the ramp* and the *weight* of the truck was offered on 6 occasions by the children with Asperger syndrome and on 19 occasions by the CA matched group.

In order to analyse explanations as a function of level each participant was given a score of between 8 and 32. A Mann-Whitney U-test revealed no significant differences in the level of explanations offered by the two groups.

Table 6.10: Number of explanations provided as a function of level across all 8 exemplars in the vertical movement task

Group	Level 1 Don't Know	Level 2 Surface	Level 3 Weight	Level 4 Surface & Weight	Total Explanations (8 per child)
AS N=10	23	40	11	6	80
CA N=10	15	38	8	19	80

#### 6.4. Discussion

The present study found that overall the prediction scores offered in relation to four tasks tapping physical understanding did not differ between the children with Asperger syndrome and a CA matched group. Analysis of each variable independently showed that with regards to the conflict/balance variable in the balance task children with Asperger syndrome offered more correct predictions than the CA matched group. In the trajectory task the CA matched group offered more corrections predictions with regard to the rolled variable than the children with Asperger syndrome. Analyses of explanations as a function of level reveal significant differences between groups in the floating/sinking and balance tasks. Performance across all four tasks was confounded with PIQ for the CA matched group but only had an effect in the trajectory task among the children with Asperger syndrome. Although limited this finding adds strength to the result of Study 2 showing that performance on tasks of intuitive physics is related to PIQ. However, in Study 3 this was only the case for the typically developing children. Baron-Cohen et al. (2001) note that intuitive psychology and physics are conceptually viewed as being independent of IQ nevertheless, it is important that future studies of intuitive physics take PIQ into consideration. Each task will now be discussed in turn.

The predictions offered with respect to the eight exemplars in the floating/sinking task did not differ between groups. Likewise there were no group differences in the response patterns across the four variables. Inspection of the response patterns showed that the most correct predictions were made with regard to the weight variable where children were presented with a rock and a sponge. Analysis of explanations as a function of level revealed that the CA matched group offered significantly more

advanced explanations across the eight exemplars than the children with Asperger syndrome. Inspection of the total number of explanations offered across the task revealed that children with Asperger syndrome were more likely to provide an 'don't know' response than the CA matched group. In line with previous work (i.e. Biddulph, 1983) the causal explanations offered by both groups were object-based. Consistent with the pattern found by Howe et al. (1990), both groups of children offered more explanations based on wrong object properties than relevant object properties. This is not surprising since the latter are defined by correct answers thus there is less scope for variability. In a similar vein, both groups of children focussed on similar salient object properties to correctly explain why an object might float/sink, the most frequent being weight. Focus on the object-liquid relationship was minimal yet was offered on a few more occasions by the children with Asperger syndrome. In contrast to some previous work (i.e. Kohn, 1993; Laurendeau & Pinard, 1962; Rodrigues, 1980; Piaget, 1930), but in line with other studies (i.e. Biddulph, 1983; Stephans et al., 1986, Howe et al., 1990), no child in this study made a reference to relative density. Rather than reflecting a lack of understanding it has been suggested that children's emphasis on object-properties may be an artefact of the methodology. Howe (1998) suggests that experiments where the objects are varied but the liquid remains constant may inadvertently focus a child's attention on object properties. Future research may gain a more reliable insight into children's understanding of density by including more than one liquid.

With regards to the balance scale task, analysis of children's predictions across the eight exemplars revealed no significant group difference. When response patterns were analysed for each variable independently a significant group difference was found in the conflict-balance variable. Here children with Asperger syndrome were more likely to predict the correct outcome than the CA matched group. Interestingly the ability to solve a conflict-balance problem was not evident in Siegler's sample of children until the age of 16-to-17 years. In line with Siegler (1976) the most correct predictions were made with regard to the weight variable where both groups frequently predicted that the arm with the greatest number of weights would descend. However in contrast to his results, this study reported a lower number of children predicting the correct outcome with regard to the distance variable and a higher number of correct predictions with regard to conflict-weight problems. Analysis of explanations as a function of level revealed that across the task the CA matched group gave more

advanced explanations than the children with Asperger syndrome. Inspection of the number of explanations as a function of level revealed that the children with Asperger syndrome were more likely to produce a 'don't know' response and that the CA matched group were more likely to offer the most advanced explanation based on both weight and distance. Thus overall, the children with Asperger syndrome were more likely to correctly predict the correct outcome of the most difficult problem (i.e. conflict-balance) than their CA matched peers. However, this more advanced level of understanding was not reflected in their explanations that are more dependent on conceptual understanding. With regards to the explanations the results showed that the CA matched group achieved more advanced scores thus more advanced understanding.

In the trajectory task the number of correct predictions offered across all eight exemplars did not significantly differ between groups. When response patterns were analysed for each variable independently a significant group difference was found in the rolled variable whereby the CA matched group were more likely to offer correct predictions than the children with Asperger syndrome. Overall, inspection of response patterns showed that, in contrast to the findings of McCloskey, Washburn and Felch (1983), both groups offered slightly more correct predictions with respect to the carried variable. When children's predictions were re-categorised according to Kaiser, Proffitt and McCloskey's findings (1985), no group differences were found. The response patterns showed that children with Asperger syndrome were less likely to predict a wrong trajectory but were more likely to be wrong with regard to exemplars from the rolled variable. This is surprising because research suggests that an understanding of the trajectory of a ball rolling from a stationary object should develop before the understanding of a ball falling from a carried object (Kaiser, Proffitt & McCloskey, 1985). Children with Asperger syndrome were more likely to offer a straight down prediction with regard to the carried variable than the rolled one. This may be because the immediate lack of a supporting surface in carried objects brings children's intuitive ideas about gravity into play (see Chapter 3). Interestingly, both groups frequently predicted that the ball would fall in a parabolic path even although research has shown that undergraduate students often fail to predict parabolic paths (McCloskey, 1983). However, it should be noted that task methodology could have facilitated performance.



After each exemplar children were shown the correct trajectory by the experimenter thus the children may have used this as a template for subsequent predictions.

Analysis of children's causal explanations in the trajectory task revealed no significant group difference. Inspection of the number of explanations offered by each group as a function of level showed that the CA matched group were more likely to offer an incorrect response than the children with Asperger syndrome. Inspection of the data also revealed that children with Asperger syndrome offered more explanations referring to a parabolic curve than their CA matched peers. However, on the whole this level of explanation was comparatively lacking in relation to the high number of predictions of a parabolic curve. This observation supports the suggestion that task methodology may have been facilitating children's predictions. However, importantly, although the feedback given to the children after each exemplar may have promoted their predictions it would not have helped advance their explanations.

In the vertical movement task the number of correct predictions offered across the eight exemplars did not differ between groups. This task proved challenging and most children could only correctly predict the outcome of two exemplars from both variables. Analysis of children's explanations as a function of level revealed no significant group difference. Inspection of the number of explanations at each level revealed that the CA matched group made more advanced explanations based on both the ramp's surface and the weight of the truck than the children with Asperger syndrome. Despite Howe's (1998) assertion that children under the age of 12 have no idea about the forces that oppose motion, explanations that referred to the ramp's surface to explain the movement of the truck were offered frequently by both groups of children. References to the weight of the truck were offered on few occasions despite the absence/presence of the marbles (i.e. weight) being very salient.

Overall, children with Asperger syndrome and a CA match group did not significantly differ when asked to predict the outcome of physical phenomena. Analysis of children's explanations found that the CA matched group offered more advanced explanations in the floating/sinking and balance tasks. However, an overall inspection of the number of explanations offered as a function of level revealed that children with Asperger syndrome were very capable of giving explanations based on physical causal

reasoning. This finding sits in contrast to the results from investigations into the explanations offered by high-functioning children with autism with regards to psychological concepts (Happe, 1994b; Loveland, Pearson, Tunali-Kotoski, Ortegón & Gibbs, 2001; Reiffe et al., 2000; Tager-Flusberg & Sullivan, 1994). As a result this study further supports the evidence of a dissociation between the domains of psychology and physics among children on the autistic spectrum.

This study also highlights potential benefits in using both predictions and explanations to investigate children's causal understanding. For example, in the balance task children with Asperger syndrome were more likely to correctly predict the outcome of the most difficult problem however, analysis of the number of explanations as a function of level granted the CA matched group with a higher level of understanding. Likewise, the predictions made by both groups in the vertical movement task did not differ between groups however inspection of the number of explanations as a function of level indicated that the CA matched group offered more advanced explanations. These findings alert caution to studies solely based on predictions; it may be the case that they cannot fully reflect children's understanding. In a similar vein, the total number of Level 1 explanations indicated that with regard to the floating/sinking and balance tasks children with Asperger syndrome were more likely to elicit a 'don't know' response. However, on the basis of their predictions it cannot be concluded that they have no understanding of the topics under scrutiny; they performed in a similar fashion to the CA match group. This raises an important issue regarding the relationship between implicit and explicit knowledge. It would be erroneous to assert that failure to offer an explanation equals lack of understanding and a lack of theoretical knowledge as argued by Gopnik et al. (2000). In the case of children with Asperger syndrome their lack of social skills may come into play in the testing situation and inhibit the production of explanations. This may also have accounted for the higher frequency of Level 1 explanations among children with Asperger syndrome in three of the tasks. This limitation may be over come by the inclusion of forced-choice methodology in any future research (for an example of this method see Williams & Binnie, 2002).

Despite some researchers concerns over children's ability to give explanations (i.e. Bullock et al., 1982) this study found there to be no difficulty on the part of the child to

explain. In-keeping with the assertion that investigating children's explanations is both easy and revealing (Wellman, Hickling & Schultz, 2000), it was found that on many occasions children from both groups would often spontaneously explain the reason behind their prediction before being asked by the experimenter to do so. Furthermore, this study showed that in contrast to the explanations offered by children with high-functioning autism with respect to psychological (among others, Happe, 1994b) and biological phenomena (Gopnik et al., 2000), their explanations with regard to physical phenomena were, on the whole, based on the physical domain of understanding. These conflicting results cannot be explained by verbal abilities since Gopnik et al.'s work reports a similar mean VIQ score as the present study. As a result, consideration must be given to the argument that children on the autistic spectrum have a comparative strength in utilising language to offer explanations about physical phenomena as opposed to their ability in the domains of biology (e.g. Gopnik et al., 2000) and psychology (e.g. Happe, 1994b; Loveland et al., 2001; Reiffe et al., 2000; Tager-Flusberg & Sullivan, 1994).

The finding that children with Asperger syndrome can correctly make predictions and express explanations about physical phenomena is evidence that they have an understanding of this domain (see Keil, 1999). Many authors subscribe to the view that the understanding within a domain is theoretical (see Chapter 1) and argue that, in part, theories are responsible for generating explanations (Wellman, Hickling & Schultz, 2000). Therefore on the basis of children with Asperger syndrome's ability to offer explanations about physical phenomena in a similar fashion to a CA match group, it could be argued that they have a theoretical understanding of physics. The issue of theoretical knowledge is pertinent to all of the three studies reported in this thesis and as a result will be discussed further in Chapter 7.

#### **6.4.1. Conclusions**

This study comprised an exploration of the predictions and explanations given by children with Asperger syndrome with regard to four physical concepts. Results showed that children with Asperger syndrome were overall just as correct in their predictions about physical phenomena as a comparison group of typically developing CA and gender matched children. Additionally, on the whole the explanations offered in support of predictions were similar across groups. These findings are in contrast to

studies investigating explanations in the domain of psychology among high-functioning individuals with autism. They also add to the small number of studies revealing intact intuitive physics among children on the autistic spectrum. However, in contrast to some research the results fail to support the claim of superior understanding among this group (as proposed by Baron-Cohen, 2000a; Baron-Cohen et al., 2001).

In general, the methodology adopted in this study of including a prediction and explanation component was both useful and revealing and, in combination, these methods could benefit research on children's understanding. Indeed, it may be the case that studies must use both methods in atypical and typically developing children in order to get a fuller description of intuitive physics, one that is comparable with the literature regarding intuitive psychology. As well as adding to the literature on children's understanding of physics the combination of these techniques may also provide a means of gaining information on the theoretical status of physics knowledge in children on the autistic spectrum and in typically developing children. As highlighted in Chapter 3 this area of work is at present extremely limited.

The final chapter of this thesis, Chapter 7, draws together the results of the three empirical studies reported in this thesis in an attempt to resolve two key research questions. The first question relates to the nature of cognition and whether it can be described as domain-specific. The second question focuses on whether children on the autistic spectrum have an intact or superior understanding of intuitive physics. The empirical answers to these questions, achieved in this thesis, have many practical implications that will also be discussed in the concluding chapter.



## CHAPTER 7

### GENERAL DISCUSSION

#### 7.1. Aims of this Thesis

Utilising the research tradition from the field of developmental psychopathology, it was the aim of this thesis to further our understanding of the structure of cognition in typical and atypical children. Cognition is assumed by many theorists to develop in a domain-specific manner. This stance holds that knowledge is constructed specifically in relation to the domain in question. In order to investigate this theoretical position, the empirical work in this thesis has focussed on the dissociation in cognitive functioning between the domains of psychology and physics present among children on the autistic spectrum. It is important to note that this thesis took the approach of investigating high-functioning children with autism. High-functioning autism and Asperger syndrome are viewed as being similar variants on the autistic spectrum (see Chapter 1) therefore comparisons amongst the three studies in this thesis can be made. The focus on this specific group within the autistic spectrum allowed an examination of the dissociation between psychological and physical understanding in a relatively pure form without the presence of other cognitive factors that might influence the findings. However, this sub-group only represents a small minority of individuals diagnosed on the autistic spectrum and as a result limits the generalisability of the findings reported here.

It is the purpose of this chapter to draw together the results from the three studies presented in this thesis. However, this chapter will not reiterate previous discussion sections. Instead focus will be given to the main findings and these will be integrated and examined with respect to the domain-specific perspective of cognitive development. Comparisons will be made between the domains of psychology and physics. Following this, focus will be given to intuitive physics knowledge and pertinent issues such as its theoretical status among children on the autistic spectrum will be discussed. Additionally, consideration will be given to the possible reasons why children on the autistic spectrum may have a superior ability to reason about physical compared to psychological phenomena.

## **7.2. Theoretical Implications: Evidence for Domain-specific Cognition**

The first chapter in this thesis set the research in context by describing the dichotomy between domain-general and domain-specific theoretical accounts of cognitive development. To recap: domain-general accounts propose that children's knowledge develops through a fixed sequence of broad, across task and across domain structures, resulting in the child's reasoning being uniform and very homogeneously 'stage-x-like' (Flavell, 2000). In contrast, domain-specific accounts propose that cognitive development proceeds somewhat independently in different content areas. This approach predicts that children will reason in a different fashion across domains than a solely domain-general theory of development would allow. Studies 1 and 2 of this thesis directly investigated these two accounts by examining cognitive reasoning in the domains of psychology and physics in children with autism and in typically developing children.

The results from Studies 1 and 2 showed that children with autism have a cognitive impairment in the domain of psychology. Study 1 showed that they performed more poorly than pre-schoolers (who were approximately five years younger) and than children with Down syndrome (who exhibited a lower mean receptive vocabulary score) on tasks of false belief and perception. Additionally, Study 2 found that children with autism performed poorer than four comparison groups (pre-schoolers, seven- and ten-year-olds, and a CA matched group) on a range of intuitive psychology questions involving concepts such as the recognition of basic emotions.

As well as impairments in the domain of psychology, Studies 1 and 2 also found that children with autism demonstrate at least an intact ability, and possibly a superior ability, to reason about phenomena from the domain of physics in comparison to typically developing children. In Study 1 they performed at ceiling level on a false photo task and performed similarly to pre-schoolers and children with Down syndrome on a task investigating the workings of a balance scale. Furthermore, not only did Study 2 show that children with autism (with a mean CA of 6.3 years) opted for the physical causal picture to complete both physical and psychological picture-sequences. Moreover, Study 2 showed that they outperformed a CA matched group as well as a group of pre-schoolers and seven-year-olds on a multiple-choice task tapping a range of physical concepts such as object motion and how things work. In fact,

findings showed that they performed in a similar fashion to a group of ten-year-old children (who were approximately four years older).

In addition to the finding of Studies 1 and 2, Study 3 reported that children with Asperger syndrome offered similar predictions with regard to the four physical concepts of floating/sinking, balance, trajectory and vertical movement as a CA matched group. In addition, the explanations they offered to support their predictions were based on physical causal reasoning. This finding contrasts with work reporting an inability of high-functioning children with autism to offer explanations about psychological concepts (e.g. Happe, 1994b; Loveland et al., 2001; Reiffe et al., 2000; Tager-Flusberg & Sullivan, 1994) thus further supporting the evidence of a dissociation in understanding between the domains of psychology and physics among this group. Taken together the evidence from the three empirical studies presented in this thesis shows that in contrast to typically developing children, children on the autistic spectrum have discontinuous reasoning abilities between at least two domains of knowledge. These findings support the underlying assumption behind the domain-specific account of cognitive development.

With respect to the three cognitive theories specifically associated with autism (discussed in Chapter 1), this thesis lends support to the theory of mind hypothesis which advocates that the ability to attribute mental states to oneself and others is impaired in children on the autistic spectrum. Inherent in this account is that other areas of cognitive functioning will be intact, just the pattern of results found in Studies 1 and 2. In contrast, the executive functioning and central coherence accounts of autism advocate that domain-general cognitive processes are to blame for the impaired ability to reason about mental states. Both accounts argue that these domain-general deficits affect learning in all areas and are not supported by findings that children on the autistic spectrum can reason in a similar fashion about intuitive biology (in Study 1) and intuitive physics (in Studies 1, 2 and 3) as typically developing children.

However a cautionary note must be made. It is assumed that across domains tasks are equal in the demands that they place on the abilities embodied in executive functioning and central coherence. Although great effort was made to take this issue into account when designing tasks, the three different cognitive accounts of autism were not the

primary focus of this thesis. Thus it cannot be confidently concluded that tasks pertaining to the different domains employed in this thesis did indeed place similar demands on executive functioning and central coherence. For example, in Study 1 the poorer than expected performance of the children with autism on the perception task was perhaps a result of the high executive functioning demands inherent in the task chosen. Along similar lines, previous work has granted children with autism an understanding of desire (Baron-Cohen, 1991; Tan & Harris, 1991) but when the executive functioning demands of the task were increased, the performance of the children with autism was greatly reduced (Russell et al., 1991).

Despite this potential limitation, on the whole the evidence presented in this thesis shows that children on the autistic spectrum demonstrate an uneven profile of competence across the domains of psychology and physics. This supports the view that cognition develops in a domain-specific fashion and raises several theoretical questions about the nature of core domains. For example, is knowledge within the domain of physics structured similarly to knowledge in the domain of psychology and moreover, is it structured similarly among children on the autistic spectrum and typically developing children? The following section will provide an initial attempt to answer these questions.

### **7.3. Comparisons of Intuitive Physics and Psychology**

Having found that children on the autistic spectrum and typically developing children can reason about physical phenomena, questions regarding the structure of this domain arise. Primarily, consideration must be given to whether the domain of physics bears any structural similarity to the domain of psychology on which so much research attention has been based.

Intuitive psychology and physics are seen by many as core domains of cognition that on the one hand develop alongside one another but on the other are distinctly different (see Carey & Markman, 1999; Sperber, Premack & Premack, 1995). This characteristic is best illustrated by Leslie (1994) who views these areas as being driven by two independently functioning modules (i.e. ToMM and ToBy) that are a part of an infant's core cognitive architecture. As indicated in Chapter 1, debate reigns over the precise structure of a domain and the exact processes that guide knowledge acquisition.



Nevertheless, research has shown that young children construct a number of intuitive ideas pertaining to these two domains. This knowledge allows typically developing children to reason about the world before the onset of formal schooling.

The domains of intuitive psychology and physics both encompass core concepts that are understood rapidly in infancy and apparently without much deliberation. As shown in Chapter 2, intuitive psychology quickly develops in the pre-school years and by the age of four years children hold much the same fundamental concepts as adults. Initially a domain of intuitive psychology encompasses basic building blocks that allow the infant to engage socially, such as joint attention. As development proceeds more advanced concepts emerge and at the core of many of these concepts lies the notion of belief. An understanding of belief is critical for understanding many other concepts within the domain of psychology, a key example being deception.

As shown in Chapter 3, a domain of intuitive physics also encompasses basic building blocks. In this case they essentially involve the knowledge that objects exist, and that they move in accordance with the principles of cohesion, contact and continuity (Spelke, Phillips & Woodward, 1995). However, it has been noted that more advanced concepts in the domain of physics are harder to grasp and typically develop at a later age than many of those from the domain of psychology. It has been stated that developing an understanding of physical objects and physical causation is a 'complex endeavour' (Wellman & Gelman, 1992). One reason for this may be because there is no core concept at the heart of the domain of physics. It appears to be the case that once children have acquired the basic building blocks of intuitive physics the domain does not develop into a coherent collection of understandings. Instead it appears to consist of a collection of independent ideas relating to particular types of physical phenomena. This can be highlighted by the fact that in Study 2 all participants, even the ten-year-olds, did not achieve full score in the physics condition whereas in the intuitive psychology condition near ceiling level was reached in all groups apart from the children with autism.

Study 3 investigated four concepts from the domain of physics and results showed that children with Asperger syndrome and their CA matched peers did not perform consistently across tasks. For example, performance in the vertical movement task

appeared to be worse in both groups than performance in the floating/sinking task. This finding lends substance to the fragmented nature of physics and furthermore suggests that the physical domain of understanding in children with Asperger syndrome and their CA matched peers is lacking in overall coherence. Many researchers state that a domain of knowledge by definition must be coherent. However this issue has been recently contested by Inagaki and Hatano (2002) who argue that children's knowledge may be more advanced in some sub-domains (which are similar to Karmiloff-Smith's (1992) notion of micro-domains) than others, even if those sub-domains employ the same overarching theories. They do not expect coherence across sub-domains but do expect it within sub-domains. The findings of this thesis suggest that this may especially be the case with the domain of physics. In contrast to the domain of psychology concepts from the physics domain can often be reasoned about independently. As a result, when investigating the domain of physics it may be more important to look for coherence within sub-domains rather than across the overarching domain.

The fragmented nature of the domain of physics may explain why there are more misconceptions reported in relation to the domain of physics than the domain of psychology. It has been stated by numerous authors that further learning within a domain is always constrained by previous knowledge (Pine & Messer, 2000) and thus if initial understanding is wrong further difficulties will continue to emerge. This seems especially prevalent in the domain of physics (see Kaiser et al., 1986). Although errors and misconceptions may also arise in the domain of psychology it is perhaps the case that among typically developing children they quickly become reconceptualised because of the continual interaction with people. Moreover, misconceptions in the domain of psychology will be very striking as is evident when observing children on the autistic spectrum in a social context. Within the domain of physics, however, misconceptions can still allow a child to reason and function effectively. For example, as described in Chapter 3, children appear to hold the theory that regardless of the presence of other variables, all objects will fall straight down. According to Hood (1995) this theory, albeit wrong, does in fact serve them quite well. In a similar vein, Kaiser, Proffitt & McCloskey (2000) have stated that many adults, even those who had taken high school physics classes, hold many misconceptions in physics (see Chapter 3).

In contrast to the four-year-old's grasp of intuitive psychology, which is said to be only qualitatively different to that of an adult (Hala & Carpendale, 1997), it has been argued that children's ideas about physics are incompatible with adult concepts (Carey & Gelman, 1991). The evidence suggests that intuitive physics is harder to grasp than intuitive psychology in typical development. This premise is not incompatible with the nature of domain-specific cognition since underpinning this theoretical account is the assumption that domains are structured differently.

Typically the development of intuitive psychological knowledge is quick and easy whereas the development of intuitive physics is slow and fragmented. The findings of this thesis suggest a reversal of this pattern among children on the autistic spectrum however, it must be noted that overall there is a lack of research in both typical and atypical children concerning the domain of physics, especially with regard to children's development from basic building blocks to knowledge in the pre-school and school years. As discussed in Chapter 3 much of the research on physics concepts has been conducted from an educational perspective, with the focus primarily on children's understanding in relation to the content of school tuition. In contrast, work from a domain-specific perspective is more focussed on children's intuitive reasoning about the world and how this understanding is structured. The following section therefore addresses the findings of this thesis in terms of pertinent issues within the domain-specific literature surrounding the status of intuitive physics knowledge particularly in relation to domains and theoretical knowledge.

#### **7.4. The Status of Intuitive Physics Knowledge: Domains and Theories**

Within domain-specific literature a domain of knowledge is thought to function in order to identify phenomena belonging to a single general kind that share among themselves a number of relevant properties (Hirschfeld & Gelman, 1994). Once identified the domain evokes ontological commitments and causal mechanisms allowing the generation of predictions and explanations about the phenomena in question. As already stated in Chapter 1, knowledge within a domain is bounded by constraints therefore it has been suggested that acquired knowledge within a domain should be similar, if not identical, across individuals (Inagaki & Hatano, 2002).

The findings presented in this thesis show that children on the autistic spectrum reason about many physical concepts in a similar (and as will be discussed below, sometimes more advanced) fashion as typically developing children. For example, Study 1 showed that typically developing pre-schoolers and children with autism performed similarly on tasks investigating physical representations and the workings of a balance scale. Likewise, Study 3 found that children with Asperger syndrome and a CA comparison group offered similar predictions and explanations with regards to physical concepts such as floating/sinking and object movement. Overall this evidence tentatively suggests that both groups of children have a domain of physics encompassing similar ontological commitments and casual mechanisms.

The notion of domains and theories are closely related: it is commonly agreed that domains comprise a collection of theories pertaining to the domain in question. Therefore, having concluded that children on the autistic spectrum have a domain of physics the question arises as to whether this understanding can be described as theoretical. Much of the discussion regarding theories in the cognitive developmental literature has often been vague and unspecified. Evaluating whether children's knowledge is theoretical is therefore a difficult task, not least because most theorists differ in terms of the criteria used for such an assessment. Much of this debate revolves around the notion of implicit and explicit knowledge (see Chapter 1). For example, according to Karmiloff-Smith (1992) knowledge can only be described as theoretical if it is represented at level E1 or higher whereby representations are 'open to conscious access'. Thus the verbal expression of knowledge is central to Karmiloff-Smith's definition of a theory. Likewise, Carey (1985; p201) asserts that the ability to explain is at the core of theories; she states, "it is the explanatory mechanisms that distinguish theories from other types of conceptual structures". However, others do not view the articulation of understanding as being the key to theoretical knowledge and instead see young children's understanding as being coherently organised and theoretical from birth. This view can be assigned to Leslie (1994) and Spelke (1988) who argue that theoretical knowledge stems from the activation of genetically specified modules. Gopnik and Meltzoff (1997) also describe the understanding that is present in young infants as theoretical. They suggest that infants are born with starting state theories that guide children's reasoning from a very early age.



Rather than adhering to a strict definition, Inagaki and Hatano (2002) have recently offered a much more speculative approach to the issue of theoretical knowledge. They suggest that a lax definition of a theory would entail evidence of coherent, reasonable and differentiated predictions based on proper causal mechanisms attributable to the domain in question. On this basis, evidence that pre-linguistic infants are sensitive to complex patterns in the world is enough to claim that they do have intuitive theories. Thus even although infants cannot make explicit predictions they do show signs of a basic explanatory causal schema, which according to some, is an essential component of a theory (e.g. Keil & Wilson, 2000). Inagaki and Hatano (2002) also offer a more stringent definition of a theory based on children's ability to offer causal explanations that are relevant and appropriate to phenomena pertaining to a particular domain. They state this characteristic as being stronger evidence for the possession of a theory.

As stated in Chapter 1, this thesis employed the definition of a theory as being a coherent well organised system of beliefs empowered in a causal explanatory framework that allows reasoning about phenomena in a particular domain to take place (Wellman, 1990; Wellman & Gelman, 1992). In keeping with this definition and the argument put forward by Inagaki and Hatano (2002), the results of the three empirical studies reported in this thesis suggest that children on the autistic spectrum and typically developing children do have theoretical knowledge pertaining to the domain of physics. For example, the results of Studies 1, 2 and 3 amply demonstrate that both groups of children can make predictions based on physical causal mechanisms thus passing Inagaki and Hatano's lax criteria. Moreover, Study 3 showed that children with Asperger syndrome and a CA matched group could both offer causal explanations based on the relevant physical variables inherent in the task. As a result, this finding provides evidence of children with Asperger syndrome passing the more stringent requirement for theoretical knowledge.

The identification of theory-like knowledge pertaining to the domain of physics in children on the autistic spectrum has shown that Gopnik et al.'s (2000) assertion that children with autism have a deficit with theory building per se needs revision. However the findings can be used in support of both Leslie's (1994) and Karmiloff-Smith's hypotheses (1992). Both these accounts suggest that children on the autistic spectrum have specific cognitive impairments in the domain of psychology (see

Chapter 2) whereas cognitive reasoning in the domain of physics will be unaffected (see Chapter 3).

### **7.5. Superior Intuitive Physics in Children on the Autistic Spectrum**

As well as identifying dissociation between reasoning in the domains of psychology and physics this thesis has also shown that children on the autistic spectrum have a very good grasp of intuitive physics.

Understanding of intuitive physics among children on the autistic spectrum was investigated rigorously in Study 2. Findings showed that children with autism preferred to choose a physical causal explanation in both the physical and psychological condition of a picture-sequencing task. This suggests that they may prefer to reason about causality in a purely physical way, employing this domain in relation to both psychological and physical phenomena. Moreover, Study 2 identified a superior understanding of physical phenomena among children with autism in the multiple-choice task compared to a group of typically developing children of the same CA age. In fact results showed that their performance was more in line with a group of ten-year-old children who were on average four years older.

In addition to these findings, Study 3 found that children with Asperger syndrome predicted the outcome of various physical concepts in a similar fashion to a CA and gender matched control group. Additionally, the explanations used by the children with Asperger syndrome to support their predictions were firmly grounded in physical reasoning. However, the content was not superior to that offered by the CA matched group. The absence of any superior ability on behalf of the children with Asperger syndrome may have been partly a result of the tasks employed in Study 3 being drawn from the educational literature and developed for use with typical children. The children with Asperger syndrome tested in Study 3 were not being taught the mainstream curriculum and as a result the typically developing CA matched group may have gained an advantage from carrying out similar tasks as part of their schoolwork. Likewise their experience of formal science lessons may have given them a benefit in offering suitable explanations. Nevertheless, the overall findings of the three studies reported in this thesis support the assertion of Baron-Cohen (2000a) that children on the autistic spectrum have an intact domain of intuitive physics. Moreover,

the results of Study 2 go some way to support his claim that their reasoning in relation to intuitive physics is superior in comparison to their typically developing peers.

The demonstration in Study 2 of a superior physics understanding in children with autism raises questions regarding the origins of this potential advantage. It has been suggested that the profile of good physics knowledge among children with autism may have been selected by hominid evolution since superior physics knowledge may be advantageous to an individual's inclusive fitness (e.g. tool use, hunting skills) and may even be preferentially selected despite impairments in the domain of psychology (Baron-Cohen et al., 2001). Baron-Cohen (2000a) has suggested that such a 'genetic liability' may manifest itself in either a genetically based impairment in intuitive psychology or a genetically based talent for intuitive physics.

It is the case that either of these cognitive profiles would lead children with autism to be much more interested in physical phenomena resulting in the development of expertise in non-social learning environments. Support for this premise has been found in a study by Baron-Cohen and Wheelwright (1999). They found that children on the autistic spectrum have interests that overwhelmingly represent activities with physical phenomena (see Chapter 3 for more details). It may be the case that the children's interests and obsessions are a product of a superior domain of intuitive physics and in turn may further foster the understanding of physical phenomena. In domain-specific literature the contribution of the child's environment is often deemed negligible (Hatano, 1997). However, it has been suggested that the acquisition of knowledge may be driven by goal directed activities (Hatano & Inagaki, 1997). With respect to the domain of biology, Inagaki (1990) found that raising a goldfish significantly increased children's factual and conceptual knowledge of fish and similar animals. Therefore in a similar vein, the intense interactions with physical phenomena among children on the autistic spectrum may lead them to learn efficiently in this domain since they are actively accumulating physical knowledge. Inagaki (1990) states that familiarity with a domain increases not only factual knowledge but also the conceptual organisation of the domain.

There is always the possibility that strengths in reasoning about physical concepts among children on the autistic spectrum may be a result of an advanced domain-

general ability. For example, the relationship between superior understanding of physics and the central coherence hypothesis has been discussed (Baron-Cohen, 2000a; Baron-Cohen et al., 2001; Happe, 2000). It has been suggested that superior understanding in the domain of physics may be a result of weak central coherence because this deficit would manifest itself in detailed analysis, just the sort of ability needed to reason about most physical phenomena. This argument would predict that a greater attention to detail would be evident not just with physical stimuli but with any stimuli where detail focus is needed regardless of domain however, this assertion remains to be tested. With respect to this thesis, the physics tasks employed were not overtly concerned with local details or segmentation skills but this was not the focus of thesis and it cannot be confidently concluded that the tasks did not tap such abilities. A more direct investigation is needed and at present the importance of a link between weak central coherence and the ability to reason about intuitive physics remains untested.

It is important to note that a superior ability to reason about physical phenomena would not be expected in all children diagnosed as having an autistic spectrum disorder. It is highly likely that individual differences would be evident and considering the findings of Studies 2 and 3, an understanding of intuitive physics may be linked to PIQ. It is important that future investigations of intuitive physics take this into consideration.

#### **7.6. Limitations of this Thesis and Suggestions for Future Research**

This thesis highlights the need for caution when ascribing domain-specific knowledge to children and acknowledges the difficulty in developing equivalent tasks in different domains and in equating task demands across participant groups. Comparing performance across domains, especially in atypically developing children, is a difficult endeavour in view of both the lack of homogeneity within clinical groupings and the differing diagnostic criteria applied in different countries. However, if we are to gain a better understanding of children's domain-specific knowledge, its development and its neurological bases, we need to continue to investigate possible links between these domains, both in typically and atypically developing children. Inagaki and Hatano (2002; p3) have recently stated that:



*It is contemporary researchers' hope that we can eventually build an integrated theory of conceptual development that replaces the Piagetian theory by closely studying each of these and several other core domains of thought and finding commonalities and differences among them.*

A further note of caution must be made with respect to concluding that the dissociation between intuitive psychology and physics among children on the autistic spectrum supports the position of domain-specificity. To conclude with confidence that domain-general abilities such as executive functioning and central coherence are having no role in the differentiated cognitive profile in children with autism, the tasks pertaining to the domain of psychology would need to contain no more demands on executive functioning or central coherence than tasks pertaining to for example, the domain of physics. Likewise, tasks on which children with autism perform comparatively well are not simply lacking executive functions or central coherence demands. These issues were not the focus of this thesis and thus were not fully considered.

Despite these limitations, this thesis has raised several important issues that deserve further attention. Firstly, now that a domain of physics has been identified among children on the autistic spectrum there is real need to systematically investigate whether this understanding is theoretical. The notion of theoretical knowledge has been described extensively in relation to the domain of psychology where the 'theory of mind' paradigm is commonly researched (see Wellman, 1990). Although the position of theoretical knowledge in the domain of physics has been discussed in this thesis (see Chapters 3 and 6), there is very little work solely concerned with identifying the content of this knowledge. In order to shed light on this issue, more descriptive work is needed on physical concepts in typical and atypically developing children. This is especially important because the volume of work in the domain of physics is very slim compared to the literature on intuitive psychology.

In a similar vein, whereas a large proportion of work has focussed on infant's understanding of physics (see Chapter 3) no work to date has attempted to chart the developmental pathway from the initial knowledge state concerning physical objects present in infancy to the development of more advanced physical concepts evident during the pre-school years. It has been argued that work on infants may help shed

light on how physical knowledge develops during childhood (see Spelke et al., 1992). However this assertion has not been reflected in the research undertaken. In particular, further research should try to employ early infancy techniques such as habituation/dishabituation in order to tap implicit knowledge in children with autism in an attempt to identify the basic building blocks identified in Chapter 3 with respect to typically developing children. However, the problems surrounding the age of diagnosis of autistic spectrum disorders may make this very difficult.

A preference for phenomena pertaining to the domain of physics among children with autism was shown in Study 2; in a physical and psychological condition of a picture-sequencing task they preferred to complete the picture-sequence based on physical causation. This preference may reflect the fact that in general, physical phenomena are predictable, especially in comparison to psychological phenomena. It has been suggested that children on the autistic spectrum crave predictability and sameness in order to make sense of the world and reduce anxiety (Hutt & Hutt, 1965; 1970). However, on the strength of the findings from this thesis it could be argued that children on the autistic spectrum attend to physical phenomena as result of underlying cognitive functioning involving deficits in intuitive psychology and strengths in intuitive physics. This argument sits well with observations of children with autism as 'little professors' accumulating more and more information with regard to their current (more often than not physical) preoccupation (see Baron-Cohen, 2000a). However, this needs further investigation, perhaps focussing on the behaviour of children on the autistic spectrum whilst they engage with physical phenomena. Are children with autism simply attracted to physical phenomena in order to reduce anxiety or are they conducting 'mini experiments' in an attempt to identify physical causal principles?

It was suggested earlier that the intense interactions with physical phenomena among children on the autistic spectrum might lead them to learn effectively in this domain. In order to investigate the role of experiential factors future research might look more closely at the obsessions and interests among children on the autistic spectrum. It may be beneficial to quantify them in order to correlate the time spent interacting with physical phenomena with performance on a battery of physics tasks (such as the multiple-choice task employed in Study 2). Only this type of analysis would allow a full investigation into the relationship between cognitive foundations and environmental

factors. Moreover, this type of research may be useful at both a group and individual level of analysis.

### **7.7. Educational Implications**

Discussion of domain-specific theories in general and the content of children's understanding in particular has obvious and significant implications for education. Studies of children's intuitive understanding have documented more than the few facts that children accumulate. They reveal fundamental types of understanding in children and reflect the ways in which children construe the world. An appreciation of how children's cognitive processes work may be able to help specify the appropriate content and effective methods of teaching. This is especially important with respect to children on the autistic spectrum.

Study 2 of this thesis has shown that children on the autistic spectrum have an intact and possibly superior domain of intuitive physics. This work adds to a small but growing literature of work on the strength of physical reasoning among this group. It has been suggested that detailed descriptions of what children know will be effective for designing a course of instruction because education aims to change an individual's initial intuitive knowledge to formal knowledge (Hatano & Inagaki, 1996). Thus the cognitive strength in the domain of physics among children on the autistic spectrum shown in Study 2 may provide an opportunity for learning about, among other things, psychological phenomena. For example, Temple Grandin (2000), an individual with Asperger syndrome, used the metaphor of sliding automatic doors (i.e. physics) to help her reason about social relationships (i.e. psychology). As this example illustrates, the ability to reason about physical phenomena may provide a tool for learning. As a result further investigation into the origins and structure of the domain of physics among children on the autistic spectrum may yield a positive avenue for educational interventions.

It has been concluded that "one of the most important findings of the cognitive/developmental research is that children do not come to science learning as a 'tabula-rasa' but have acquired rich knowledge about the physical world based on their everyday experiences" (Vosniadou & Ionnides, 1998; p186). As this quote suggests, the investigation of intuitive physics knowledge in typically developing children has been



identified as educationally significant, especially if studied in the early years before formal education (Howe, 1998). There is no reason why this should not also be the case for children on the autistic spectrum. It seems obvious that instruction should seize upon children's early intuitive understanding and exploit it so that children can get a sense of continuity between their own spontaneous inquiries about the world and those inquiries that are guided by formal instruction (Keil & Silberstein, 1998). The basis of children's knowledge must be used to teach children to see which arguments are plausible on the basis of what they know (Inagaki & Hatano, 2002). Thus if research continues to reveal an advantage among children on the autistic spectrum in understanding physical phenomena across a range of tasks, then the educational and therapeutic implications of this must be explored in order to capitalise on this potential cognitive strength.

### **7.8. Summary and Concluding Comments**

As well as adding strength to domain-specific theoretical accounts of cognitive development this thesis has provided a much-needed contribution to the literature on intuitive physics among children on the autistic spectrum and typically developing children. The employment of tasks traditionally situated within educational contexts has proven a useful addition to the repertoire of intuitive physics tasks used in child development research and should be utilised more in the quest for advancing our understanding of intuitive physics.

At present, many accounts of cognitive development profess that knowledge is acquired in a domain-specific fashion (Inagaki & Hatano, 2002). This thesis supports this assertion by showing that children on the autistic spectrum have difficulties with reasoning pertaining to the domain of psychology but not in the domain of physics. Studies 1 and 2 suggest that children with autism have a cognitive profile that reflects a deficit in the domain of psychology and an intact domain of physics. Moreover, Study 2 found evidence of a superior ability of children with autism to reason about physical phenomena. In addition, Study 3 showed that children with Asperger syndrome are just as correct in their predictions about physical phenomena as a CA matched group. Furthermore, in contrast to the lack of conceptual knowledge in explanations offered in the domain of psychology (e.g. Happe, 1994b), Study 3 showed that children with Asperger syndrome could produce explanations based on physical causal reasoning.



Taken together these results not only support the claims of discontinuity in development between intuitive psychology and physics among children on the autistic spectrum but also highlight the ability of this group to reason about physical phenomena.

## **APPENDIX A**

### **ETHICAL ISSUES WHEN CONDUCTING RESEARCH WITH CHILDREN**

#### **A.1. Introduction**

Before conducting any research the experimenter is responsible for making a careful evaluation of its ethical acceptability before the study is designed. This is especially the case when the research participants are children (Thomas & O'Kane, 1998). Moreover, it is particularly important when they have learning disabilities. Therefore, addressing the ethical issues appropriately was of central importance to the studies reported in this thesis. Two main issues were at large: informed consent and confidentiality.

#### **A.2. Informed Consent**

The British Psychological Society's [BPS] code of conduct (2000) was adhered to at all stages in this research. It states that when conducting research with participants who may not have the abilities to grant informed consent special safeguarding procedures are required. As a result, the present research required that prior to data collection 'by proxy' consent had to be obtained from the parents/guardians of potential participants. In practise because the research presented in this thesis was conducted in schools, consent was initially obtained from the local Education authority, the head-teacher and the class teacher before parents were approached. Despite these safeguards it was important that gaining consent from these 'adult gatekeepers' did not negate the need to inform the child and where possible also obtain consent from the child.

In order to grant informed consent parents must be informed by knowledge about the research. As a result a number of issues must be conveyed by the experimenter to the parents in order for them to make a reasoned decision about permitting their child's involvement in the research (Mason, 2000). First and foremost parents must fully understand how participation will affect their child. In the studies reported in this thesis a letter provided this information. Written details regarding the purpose of the study was given alongside details about the process of data collection (i.e. how long it would take etc.) and the intended outcome of the findings (i.e. PhD thesis, journal

publications). It was important to fully explain to parents that they have a real choice whether to allow their child to participate or not and make them understand that at any time they could withdraw their consent (see BPS, 2000; section 6.1). This point is especially important because the present research was conducted in schools and as a result many parents may feel obliged to consent. The studies reported in this thesis adopted an 'opt in' policy whereby the written consent of the parent had to be received before participation was considered.

In order to receive consent from the children included in this thesis their age and verbal ability had to be taken into account. It was important that the child fully understood that they could withdraw at any time. However, because participation in school activities is usually not optional it was important that the experimenter attended to the child's body language since a decline in motivation or avoidance of the testing situation may be a sign of consent being withdrawn.

### **A.3. Confidentiality**

In line with the BPS guidelines every effort was taken to protect the confidentiality of participants (see BPS, 2000; section 7.1). The present research maintained an individual's anonymity throughout by rendering anonymous any records that no longer needed to be personally identifiable. In addition, the individual schools involved were not disclosed and are only described by geographical area. In the three studies reported in this thesis, school records often had to be checked in order to confirm a child's diagnosis. This was never carried out without the consent of the parents and guidelines concerning confidentiality of the information was adhered to.

The data collected was never identifiable with any individual or school. Paper and computer files were always appropriately secured and never shared or used for purposes other than that intended and consented by the parents. Study 3 involved participants being video recorded. Assurances were given to parents that the experimenter would be the only viewer of these videos and that they would be destroyed once the data was transcribed or alternatively if consent was withdrawn.

#### **A.4. Overview**

Ethical guidelines cannot provide specific clear appreciation of the dilemmas that researchers face (Morrow & Richards, 1996) and many ethical considerations will be context specific. Nevertheless, it is important that researchers in psychology follow the guidelines issued by the BPS in order to protect both research participants and themselves.

#### **Bibliography**

- Bell, J. (1999). *Doing your research project: A guide for first-time researchers in education and social science*. Open University Press: Buckingham.
- The British Psychological Society. (2000). *Code of conduct, ethical principles and guidelines*. The British Psychological Society, Leicester.
- Gale, A. (1995). *Ethical issues in psychological research* (p92-112). In Coleman, A. M. (Eds). *Psychological research methods and statistics*. Longman: London.
- Greig, A. & Taylor, J. (1999). *Doing research with children*. Sage: London.
- Lewis, A. & Lindsay, G. (2000). *Researching children's perspectives*. Open University Press: Buckingham.
- Masson, J. (2000). *Researching children's perspectives; Legal issues* (p34 – 45). In Lewis, A. & Lindsay, G. (Eds). *Researching children's perspectives*. Open University Press: Buckingham.
- Morrow, V. & Richards, M. (1996). *The ethics of social research with children: An overview*. *Children and Society*, 10, 90-105.
- Thomas, N., & O'Kane, C. (1998). The Ethics of Participatory Research with Children. *Children & Society*, 12, 336-348.



## APPENDIX B

### STUDY 2: THE CONTENT OF THE EIGHT STORIES IN THE PICTURE-SEQUENCING TASK

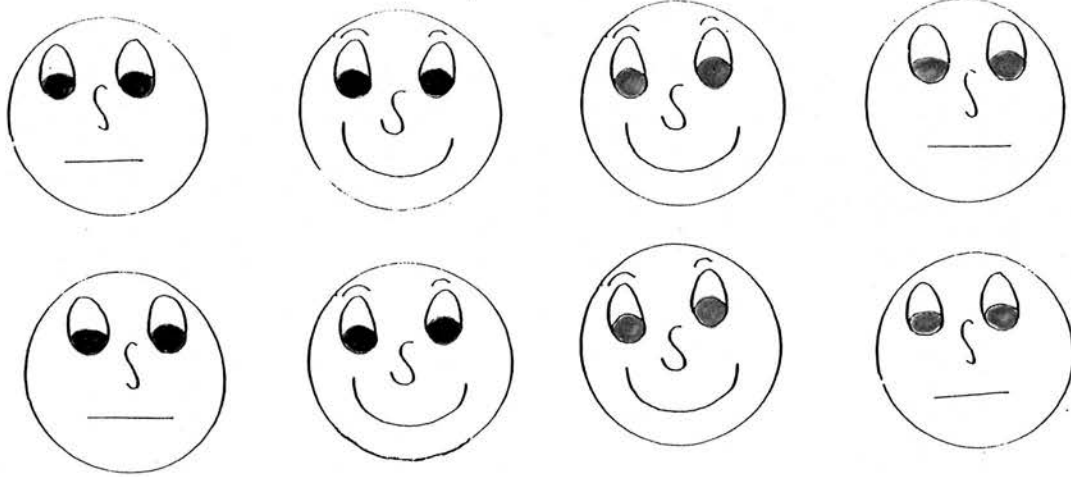
FIRST PICTURE	PSYCHOLOGICAL	PHYSICAL	LAST PICTURE
<u>Man-made artefacts:</u>			
Bulb on	Hand turning off switch	Element breaking	Bulb off
Car at top of hill	Hand pushing car	Car pushing car	Car at bottom of hill
Tap running water	Hand turning off tap	Burst pipe	Tap dripping water
Floating balloon	Hand pricking balloon	Tree pricking balloon	Burst balloon
<u>Natural artefacts:</u>			
Apple on tree	Hand picking apple	Apple falling off	Apple on ground
Flower standing	Hand cutting flower	Flower falling over	Flower stem cut
Tree standing	Hand cutting tree	Lightning hitting tree	Tree cut into two
Rock at top of hill	Hand pushing rock	Wind pushing rock	Rock at bottom of hill

## **APPENDIX C**

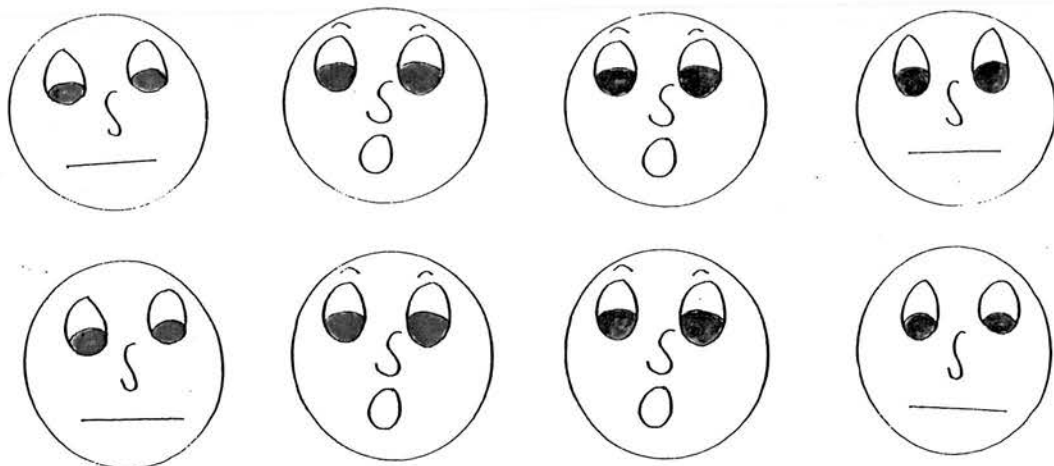
### **STUDY 2: EXAMPLES OF CATEGORISATION STIMULI FROM BOTH PSYCHOLOGICAL AND PHYSICAL CONDITIONS**

Psychological Condition

Example 1: happy/neutral

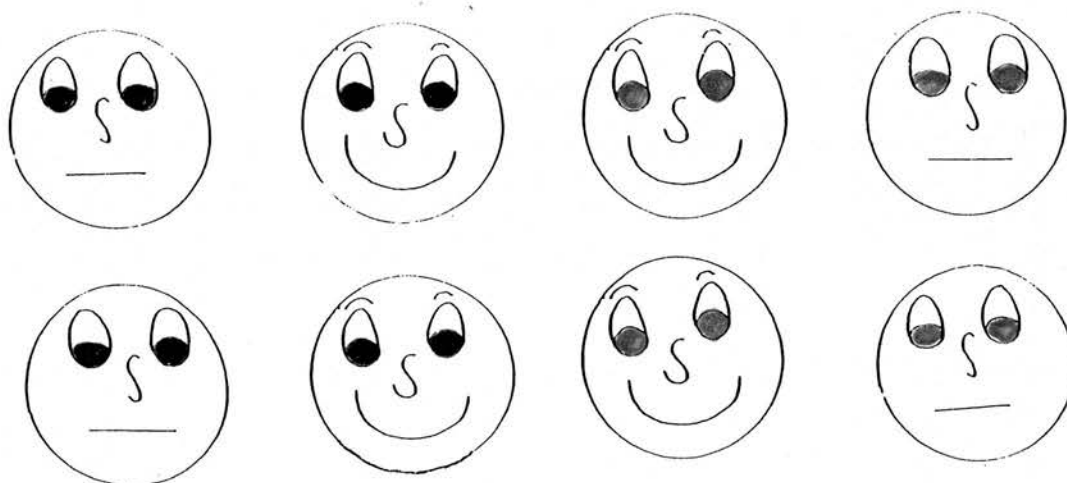


Example 2: surprised/neutral

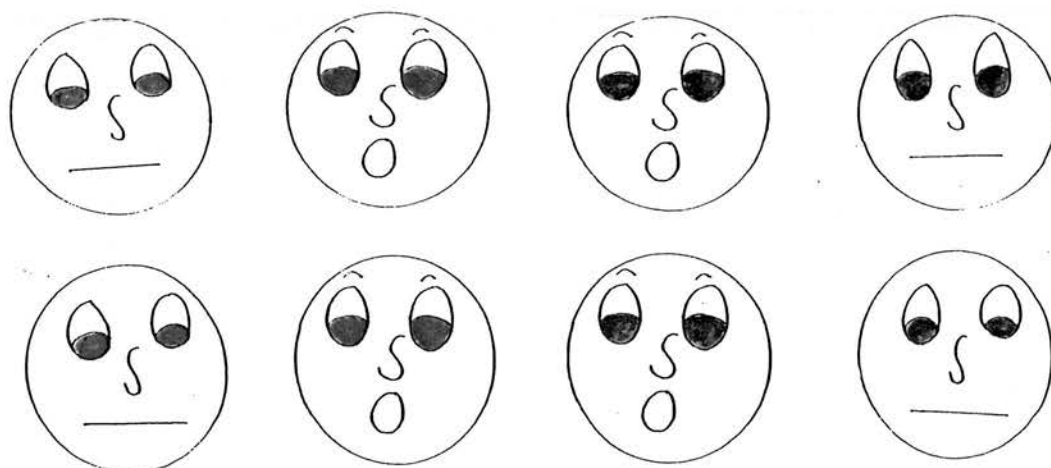


Psychological Condition

Example 1: happy/neutral



Example 2: surprised/neutral





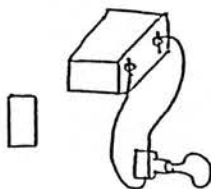
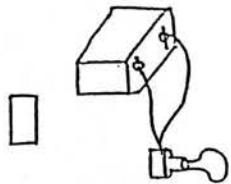
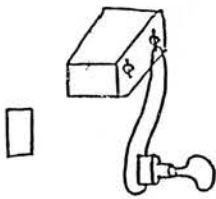
## **APPENDIX D**

### **STUDY 2: MULTIPLE CHOICE WORKBOOK**

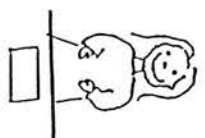
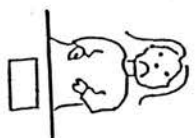
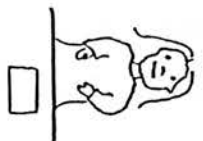
Tick the correct answer:



1) Which one will work?



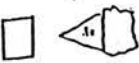
3) Which one is happy?



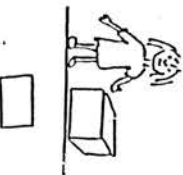
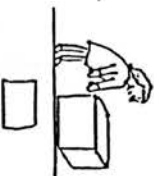
4) Where will the ball go?



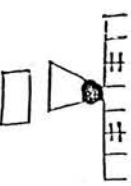
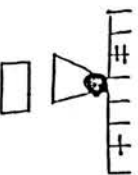
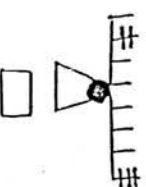
2) What does he want?



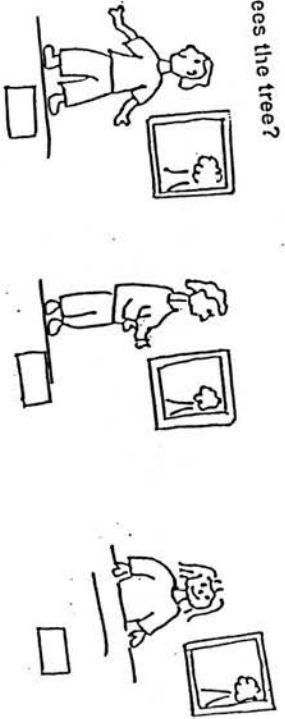
5) Which one sees in the box?



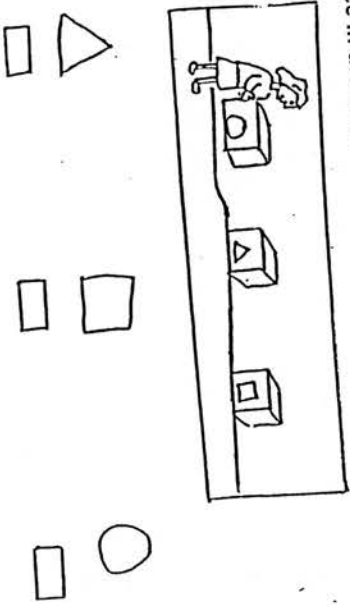
6) Which one will balance?



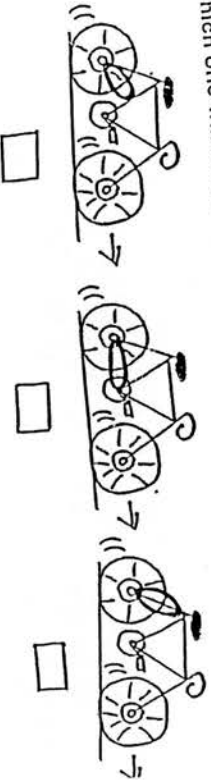
7) Which one sees the tree?



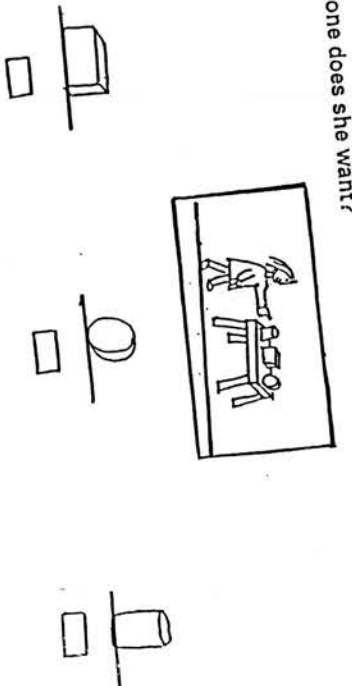
8) What does she see in the box?



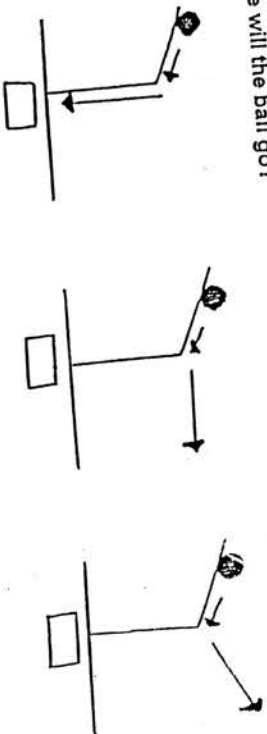
9) Which one will work?



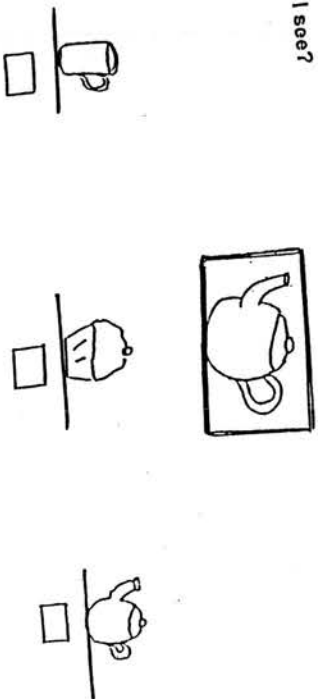
10) Which one does she want?



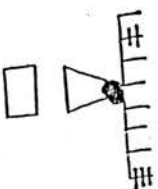
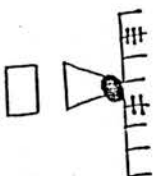
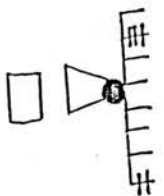
11) Where will the ball go?



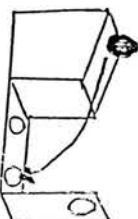
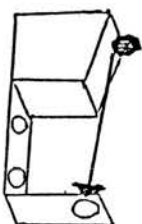
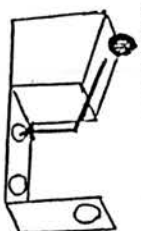
12) What do I see?



13) Which one will balance?



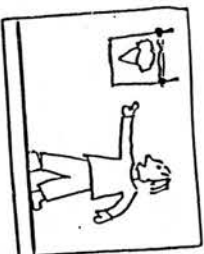
17) Where will the ball go?



18) How will she feel?



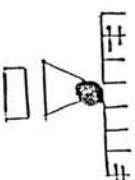
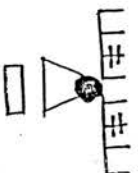
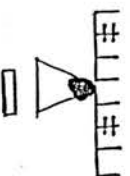
14) What does he want?



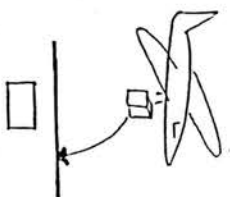
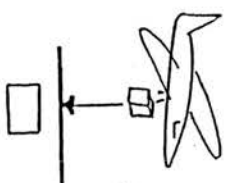
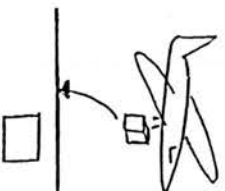
15) Which one is sad?



19) Which one will balance?



20) Where will the box land?

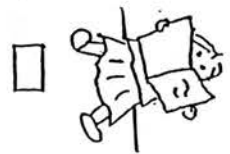
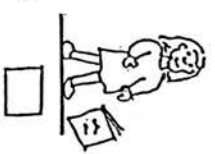


16) Which one will work?

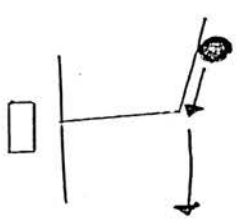
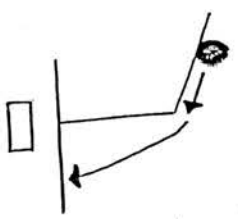
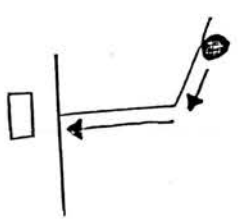




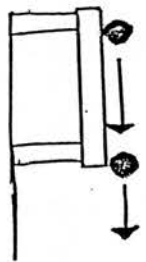
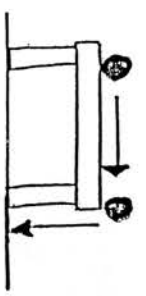
21) Which one sees the pictures in the book?



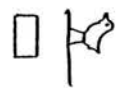
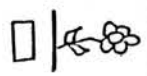
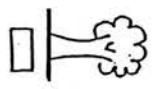
24) Where will the ball land?



22) Where will the ball land?



23) Which one does she see?



## APPENDIX E

### PUBLICATIONS

#### PAPER 1:

Binnie, L. M. & Williams, J. M. (2002). Intuitive psychological, biological and psychological knowledge in typically developing children, children with autism and children with Down Syndrome. *British Journal of Developmental Psychology*. 20 (3), 343-359. Reproduced with permission from the British Journal of Developmental Psychology, © The British Psychological Society.

#### PAPER 2:

Binnie, L. M. & Williams, J. M. (in press). Understanding of intuitive psychology and intuitive physics in children with autism and typically developing children. *Autism: An International Journal of Research and Practise*. Reprinted with permission from Sage Publications Ltd. and The National Autistic Society, 2002.



## Intuitive psychological, physical and biological knowledge in typically developing preschoolers, children with autism and children with Down's syndrome

Lyne M. Binnie and Joanne M. Williams\*

Faculty of Education, University of Edinburgh, UK

This study investigated intuitive concepts of biology, physics and psychology in typical preschoolers ( $N = 23$ ), children with autism ( $N = 20$ ) and children with Down's syndrome (DS;  $N = 18$ ). Three tasks from Peterson and Siegal (1997) (false belief (Baron-Cohen, Leslie, & Frith, 1985), false photo (Zaitchik, 1990) and innate potential (Gelman & Wellman, 1991)) were employed. A further three tasks (perception (Slaughter & Gopnik, 1996), balance (Sieglar, 1976) and illness (Kaliash, 1998)) were included to gain insight into the similarities and differences in understanding across groups of children and within each domain. Preschoolers performed well on both the intuitive psychology tasks, children with autism performed poorly on these tasks, and children with DS performed well on the perception task but poorly on the false belief task. By contrast, performance on the physics and biology tasks was not significantly different across groups. These findings support the argument that cognitive development is domain-specific and highlight the need for further research in this area.

### Domain specificity in typical development

Many researchers of cognitive development have come to adopt the idea that children's knowledge acquisition may proceed through domain-specific rather than purely domain-general processes (e.g. Fodor, 1983; Gunnar & Maratsos, 1992; Karmiloff-Smith, 1992; Keil, 1999). Studies have shown that, typically, children develop implicit and explicit intuitive knowledge that constitute various domains of knowledge (Carey, 2001; Wellman & Inagaki, 1997). A domain has been characterized in a range of ways by different researchers (see Wellman & Gelman, 1992), but is commonly held to involve a set of causal explanatory mechanisms (e.g. principles or theories); ontological commitments (i.e. rules of application of mechanisms); and a set of phenomena to

which mechanisms are applied (i.e. ontology) (e.g. Carey, 1985; Gopnik & Meltzoff, 1997; Hirschfeld & Gelman, 1994). The concepts within a domain may include 'core knowledge' (e.g. Spelke, Breilinger, Macomber, & Jacobson, 1992) that comprises fundamental implicit and possibly innate principles that may be evident in infancy depending on the specific domain.

The focus of the present study is on three 'core domains' of intuitive knowledge relating to psychological, physical and biological phenomena (Carey, 2001; Wellman & Gelman, 1992; Wellman & Inagaki, 1997). Intuitive psychology involves knowledge of persons and their mental life including core infant knowledge, such as shared attention (Mundy & Crowson, 1997) and developmentally higher level knowledge, such as personological traits (Heyman & Dweck, 1998). The domain of physics is thought typically to encompass understanding of physical objects and their movement including fundamental knowledge of objects (e.g. Bailargeon, 2000; Spelke *et al.*, 1992) and higher level knowledge of, for example, forces (Pauen, 1996). Finally, the biological domain concerns plants and animals and their characteristics, and encompasses basic knowledge about categories of living things (Atran, 1999) and higher level concepts such as inheritance (Springer, 1999; Williams & Tolmie, 2000) and illness (Kaliash, 1999; Williams & Binnie, 2002). Typically developing children possess knowledge in each of these domains by the age of 4 years and evidence suggests that intuitive physical and psychological knowledge is present in infancy, whereas intuitive knowledge of biology may arise developmentally later (e.g. Carey & Spelke, 1994; Wellman & Gelman, 1992). To further explore the issue of domain-specific cognition, some researchers have begun to examine atypical development, in particular autism, in an effort to identify the relative independence of knowledge development and the acquisition processes in different domains.

### Domain-specific knowledge and autism

Research on autism has offered strong support for the notion of domain specificity in cognitive development. In relation to intuitive psychology, many of the prerequisites of psychological knowledge such as joint attention (Mundy & Sigman, 1989), preference for human auditory stimuli (Karmiloff-Smith, 1992) and pre-declarative pointing (Baron-Cohen, 1989b) are impaired among children with autism. Subsequently, children with autism, compared to typically developing children, are less likely to attribute mental states such as knowing and believing to oneself and to others (Frith, 1989; Frith & Happé, 1994), have an inability to deceive and lie (Russell, Mauthner, Sharpe, & Tidswell, 1991) and cannot make 'appearance-reality' distinctions (Baron-Cohen, 1989a) or interpret complex affective states (Baron-Cohen, 1991; Baron-Cohen, Spitz, & Cross, 1993; Hobson, 1986). Moreover, some studies suggest that this deficit in intuitive psychology is exclusive to autism when compared to children with Down's syndrome (DS) (Baron-Cohen, Leslie, & Frith, 1985). However, other studies have shown that children with DS and other atypical developmental syndromes (such as Williams syndrome) perform below typical preschoolers but similarly to children with autism on intuitive psychology tasks, indicating the need for further research in this area (Tagger-Flusberg & Sullivan, 2000; Yirmiya, Solomonica-Levi, Shulman, & Pilowsky, 1996; Zelazo, Burack, Benedetto & Frye, 1996).

Further evidence for the domain-specific cognition argument derives from observations that children with autism have an intact (and perhaps advanced) understanding of intuitive physics (Baron-Cohen, 1997, 2000). Some evidence from

\* Requests for reprints should be addressed to Joanne Williams, Lecturer in Psychology, Faculty of Education, St Johns Land, Holyrood Road, Edinburgh EH8 8AQ, UK (e-mail: Jo.Williams@education.ed.ac.uk).

the families of children with autism suggests that their obsessive behaviour often focuses on mechanical objects (Baron-Cohen & Wheelwright, 1999) and family histories have revealed high rates of engineering professions (Baron-Cohen, Wheelwright, Sott, Bolton, & Goodyer, 1997). Another strand of evidence involves direct studies of intuitive physical knowledge among children with autism. These have revealed that, compared to preschoolers, children with autism perform significantly better on questions involving physical causation, but more poorly on ones involving intentional causation (Baron-Cohen *et al.*, 1985). Children with autism are also more likely than typically developing matched controls to attribute physical functions to the brain, rather than mentalistic functions (Baron-Cohen, 1989a). Furthermore, children with autism demonstrate an ability to understand physical representations created by mechanical objects such as a camera (Leekam & Perner, 1991; Leslie & Thaiss, 1992). Thus, when comparing performance on a 'false photo' task and a standard 'false belief' task (two tasks that are similar structurally but assess understanding in different domains), children with autism pass the intuitive physics task but fail the intuitive psychology task. However, evidence supporting intact intuitive physics among children with autism has been heavily reliant on the 'false photo' task and consequently more research is required to investigate how children with autism understand other physical phenomena. Additionally, whereas some intuitive psychology research has included comparison groups (e.g. DS), this has not been the case in relation to physics and thus little is known of physics knowledge among other groups of atypically developing children. Hence, further research is required to ascertain whether intact physics is particular to children with autism, and to investigate the development of this domain among children with other forms of atypical development.

Research has now begun to consider the development of intuitive biology knowledge among children with autism (Gopnik, 2001; Gopnik, Carps, & Meltzoff, 2000). In a study of high functioning children with autism, factual biological knowledge and biological explanations were explored. Children with autism were found to apply incorrect classifications when categorizing living vs. non-living exemplars (Gopnik *et al.*, 2000). Furthermore, children with autism referred to movement as a defining characteristic of living things more than comparison children and referred to biological processes less than comparison children in their explanations for classifying an exemplar as a living thing (Gopnik *et al.*, 2000). It was concluded that children with autism may 'possess a less well-developed theory of biology than do typically-developing children' (Gopnik *et al.*, 2000, p. 68). The finding that intuitive biology may be limited, while intriguing, requires further exploration. First, the same results require replication in children with autism who may have language difficulties and cannot therefore offer explanations. Second, research is required to explore whether difficulties with intuitive biology are specific to children with autism or whether they are also evident among children with other developmental disabilities (e.g. DS). Johnson and Carey (1998) showed that individuals with Williams syndrome had relatively intact factual biology knowledge compared to typically developing 10-year-olds but that their 'theoretical' knowledge was at the level of 6-year-olds. However, no comparison with children with autism was made in this study.

### Comparative studies across domains

There is a relative lack of research comparing the development of children's understanding across different domains. In part, this lack of cross-domain comparison

within particular children can be attributed to the assumption among some researchers that domains are independent from one another. It may also be the case that intrinsic methodological difficulties of constructing tasks that assess equivalent levels of understanding across domains has led researchers to avoid such comparisons. Moreover, evidence indicates that intuitive biology may develop over a different time course than intuitive physics and psychology, exacerbating the problems in designing age-equivalent tasks across the three domains. However, despite these difficulties, it is important to examine the independence of understanding across these domains to address fully the fundamental questions concerning the origins and possible neurological foundations of domain-specific cognition.

Relatively few researchers have attempted comparative studies of intuitive psychology, physics and biology. One series of studies was conducted by Wellman, Hickling, and Shult (1997, 2000), who investigated typically developing children's explanations of events (e.g. movement) and concluded that young children could utilize causal reasoning from the three domains interchangeably and flexibly. In a similar vein, Peterson and Siegal (1997) examined different groups (deaf children, children with autism and typically developing preschoolers) of children's performance on three tasks. Each task related to a separate domain of knowledge: psychology (false belief; Baron-Cohen *et al.*, 1985), physics (false photo; Zaitchick, 1990) and biology (innate potential; Gelman & Wellman, 1991). Their results showed that preschool children and deaf children from signing families performed better on the intuitive psychology task than children with autism and deaf children from non-signing families. However, all groups of children performed similarly on the physics and biology tasks.

### The present study

To explore the characteristics of domain-specific knowledge pertaining to psychological, physical and biological phenomena among typically developing preschoolers, children with autism and children with DS, the structure of Peterson and Siegal's (1997) study was replicated. The similarities and differences within and between domains of knowledge were explored by employing three further tasks (one from each domain). The additional tasks were conceptually different to the ones chosen by Peterson and Siegal, to provide a more robust indicator of children's understanding within each domain. Developmental data suggest that the process of knowledge acquisition within a domain involves some concepts being understood before others. For example, young children's early domain of psychology includes knowledge of desire, perception and emotion, but does not include knowledge of belief. Likewise, a 4-year-old's understanding of biology typically includes animals but rarely plants (Wellman & Gelman, 1992). The pragmatic approach taken to equate tasks in each domain was to identify tasks that are normally passed in typically developing children by the age of 4 years old. Thus, all tasks employed in this study were of preschool level, although one task in each domain was chosen to tap slightly more sophisticated concepts than the other. It was expected that understanding of perception would precede false belief; understanding of false photo would precede balance; and an understanding of innate potential would precede illness (Wellman & Gelman, 1992). In each case, the latter task assessed more sophisticated knowledge within the domain in question.

This study compared children with autism, typically developing 4-year-olds and children with DS. Numerous studies have highlighted a domain-specific deficit in intuitive psychology among children with autism (Wellman & Lagattuta, 2000), and it



has been suggested recently that their intuitive biology is less well developed than that of typically developing children (Gopnik *et al.*, 2000). Children with DS have been included because they exhibit domain-general cognitive deficits and, despite within-group variation, do not usually progress beyond the cognitive capabilities of a typically developing 8-year-old (Wishart, 1999). It was expected that typically developing 4-year-olds would pass at least the tasks set at preschool level in each domain; by contrast children with autism were anticipated to show impaired performance on psychology and biology but intact physics performance. Children with DS were expected to reveal lower performance than typically developing preschoolers across all tasks.

## Method

### Participants

The participants were 61 children from one nursery, three mainstream and four special schools covering a wide range of socio-economic catchment areas in Edinburgh and the Lothians. The participants comprised three groups: 23 typically developing preschoolers, 20 children diagnosed with autism (according to DSM-III-R or ICD-10 criteria); and 18 children with DS. Table 1 details the sample characteristics. All participants were administered the British Picture Vocabulary Scale (BPVS-II; Dunn, Dunn, Whetton, & Burley, 1997) to ensure that they had a verbal mental age (VMA) of 4 years (VMA scores are usually lower than non-verbal mental age scores). This has been the measure of choice in a number of studies of children with autism (e.g. McGregor, Whiten, & Blackburn, 1998; Perner, Frith, Leslie, & Leckam, 1989; Petersen & Siegal, 1998).

**Table 1.** Diagnostic groups: number (N), mean chronological age (CA) and mean verbal mental age (VMA) in years, months

Diagnostic group	N	CA (range)	V-M-A* (range)
Preschoolers	23	4.5 (4.1–5.0)	5.4 (4.02–6.08)
Autism	19	10.0 (6.11–12.0)	5.4 (4.0–7.07)
Down's syndrome	18	13.1 (9.0–17.5)	4.6 (4.0–6.01)

\* BPVS-II.

### Materials

Published tasks were employed and every effort was made to maintain their original detail. However, these tasks were originally designed for use with typical populations and therefore some changes were essential. Two main additions were made to ensure consistency of task demands and to increase their appropriateness for use with typically developing children.

First, each of the tasks employed a 'reality control' (RC) question to establish that participants were attending to the task, and a 'memory control' (MC) question to ensure that failure would not result from memory problems. The control questions were presented randomly before the test question (TQ); previous research suggested that this would not facilitate performance (Zaitchik, 1990).

Second, to eliminate the need for verbal answers, pictorial response options were designed to accommodate the preference for non-verbal modes of response among

children with autism and to omit response biases in verbal data owing to short-term memory difficulties experienced by children with DS (Freeman & Hodapp, 2000). For each task, participants were randomly presented with three drawings and instructed to point to the correct answer. On the majority of tasks only one option was correct; therefore, the level of success predicted through chance was 33%. However, previous literature has shown that understanding of balance scales and illness progress developmentally. Therefore, additional analyses on these two tasks were performed exploring group differences in incorrect, partially correct and fully correct responses.

## Psychology tasks

### Perception

Slaughter and Gopnik's (1996) perception task was employed, with one additional change: a toy boat was used instead of a toy cat. Participants were introduced to a teddy bear and told that 'he is sleepy so sometimes he will nap and sometimes he will play'. He was then placed under the table. Sitting at a table, participants were asked to view a green toy boat through a red filter (the boat looks black). They were then asked to move seats in order to view the toy boat from the opposite side, i.e. not through the filter (the boat looks green). Following this, the teddy awakes and wants to play. He was placed in the first seat and viewed the boat through the red filter. Participants were presented with a drawing of a red boat, a green boat and a black boat and were asked to:

- RC: 'point to the colour of boat that you see now when you are sitting in this chair'  
 MC: 'point to the colour of boat that you first saw when you were sitting over there in that chair'  
 TQ: 'point to the colour of boat that the teddy will see when he is sitting over there in that chair'.

### False belief

Baron-Cohen *et al.*'s (1985) 'Sally/Anne' test of false belief was employed. In the standard procedure, a girl doll called Sally places a marble under a basket and leaves the room. Before Sally re-enters the room, another girl doll moves the marble, placing it under a box. Participants were shown three drawings: a box, a basket and a container and asked to:

- RC: 'point to where the marble is really'  
 MC: 'point to where the marble was in the beginning'  
 TQ: 'point to where Sally will look for her marble'.

## Physics tasks

### False photo

This task was a version of Zaitchik's false photo task (1990) using a smaller, child-size Polaroid camera. After pre-training participants in the use of the camera (Zaitchik, 1990), the experimenter introduced a baby doll and demonstrated it being placed in a toy bath, in a toy bed and in a toy gram. The experimenter placed the baby doll in the bath and asked the participant to look through the window of the camera (at the baby in the bath) and take a picture. The picture that was produced by the camera was placed face down on the table. Once this was completed, a dummy doll was

introduced and took the baby out of the bath and placed it in the bed. In line with Peterson and Siegal (1997), the furniture designated for use in the photograph was varied across all trials. Participants were presented with three drawings of the baby in the bath, the bed and the pram and asked to:

- RC: 'point to where the baby is now'  
 MC: 'point to where the baby was when the camera flashed'  
 TQ: 'point to where the baby will be in the photo.'

#### Balance

The balance task was adapted from Siegler (1976) who reported that 5-year-olds respond on the basis of weight (partially correct, Rule I) but 9-year-olds consider both weight and distance from the fulcrum (fully correct, Rule II). Pilot work with preschoolers conducted for the present study found that all used Rule I with a small minority using Rule II.

Participants were first introduced to 'naughty teddy' and told that he wants to play. They were then pre-trained in the workings of a balance scale (a large wooden balance painted in primary colours), emphasizing the four equally spaced pegs on either side and the four rings that were all the same weight. Participants were encouraged to put the rings onto the balance 'in all the ways you can think of in order to learn how the balance works'. After approximately 3 min the experimenter fixed the balance in place with a piece of wood. Participants were told that the balance scale would not move but that they had to think about how it would look without the piece of wood. The experimenter proceeded by placing two rings on each of the second peg from the fulcrum. The 'naughty teddy' then swooped over the experimental material and 'messed up' the balance scale by moving two rings to the third peg from the fulcrum on the left-hand side of the scale only. 'Naughty teddy' rather than the experimenter made the transformation to reduce inferred experimenter demands (McGarigle & Donaldson, 1974). Participants were shown three drawings of the balance scale balancing, tipping to the right and tipping to the left. They were then asked:

- RC: 'has naughty teddy moved the rings?'  
 MC: 'point to how the scales looked before naughty teddy messed them up.'  
 TQ: 'point to how the scales should look after naughty teddy messed them up.'

#### Biology tasks

##### Innate potential

This task was taken from Peterson and Siegal (1997) and is an adaptation of an original innate potential task by Gelman and Wellman (1991). Participants were read a story about a baby animal, born to one species but raised by another:

'This is a picture of a baby animal [shown in a 'nondescript embryonic way' (Peterson & Siegal, 1997, p. 62)]. Her name is Edith. This is her mother, the dog [a realistic drawing of a dog is shown]. When she was a tiny baby, Edith went to live with a family of cats. This is the mother cat and father cat [a drawing of male and female cat was displayed] who raised her like their own baby. She lived with these cats all her life until she was grown up and she never saw another dog again. Now Edith is all grown up.'

A realistic drawing of a cat, a dog and a horse were shown and the participants were asked to:

- RC: 'point to the animal who gave birth to Edith'  
 MC: 'point to the animal who raised Edith'  
 TQ: 'point to the picture of Edith now that she is grown up.'

#### Illness

This task is based on work by Kalish (1998). He showed that typically developing children's understanding of illness causation develops over age from a preschool deterministic theory of illness to a later probabilistic understanding of causation. Since this study included a number of older participants, this developmental trend was taken into account and two correct responses with differing degrees of sophistication were provided (definitely = partially correct (Rule D); maybe = fully correct (Rule II)). Participants were read a story accompanied by pictures:

'This is Craig. He is happy playing at home [a drawing of Craig is shown]. One day his friend came over to play [drawing of Craig and his friend playing is displayed]. His friend had a cough and a runny nose. His friend had the cold. Craig played with his friend and his friend sneezed on him [drawing of Craig's friend sneezing on him is shown]. After a while Craig's friend went home [drawing of Craig waving goodbye is shown].'

Participants were shown three drawings depicting Craig as not having the cold, maybe having the cold and definitely having the cold. Since the pictures were subjective, the experimenter pointed to them as the three randomly presented choices in the TQ were given:

- RC: 'did Craig have the cold before his friend came over?'  
 MC: 'does Craig's friend have the cold?'  
 TQ: 'point to the picture of Craig after his friend goes home, will he not have the cold, maybe have the cold or definitely have the cold?'

#### Procedure

Participants were tested individually in a quiet setting. In light of Slaughter and Gopnik's (1996) point that performance on one psychological task facilitates performance on another, the two tasks pertaining to each domain were presented in sequence in order to reduce this potentially confounding effect. Note, however, that this possibility of reciprocal influence of task performance in psychology still remains, although to a lesser degree. Within this constraint, tasks were administered randomly. Participants who failed two attempts at the control questions were excluded from the study. If participants passed both control questions in a task but failed to answer the TQ, it was repeated one more time. All tasks were administered to a child on the same day in a single session lasting between 10 and 20 min.

#### Results

Children were scored correct on each of the six tasks if they identified the fully correct answer from a choice of three cards. Taking each domain of knowledge separately, children's initial scores were analysed in a task (Task 1 vs. Task 2)  $\times$  group (autism, DS, preschoolers) ANOVA. Additional classifications of the illness and balance tasks were performed to investigate degrees of correctness for subsequent non-parametric

analyses. For this purpose partially and fully correct responses were differentiated to provide a 3-point scale in each case.

Table 2. Mean performance scores for each task and participant group

Diagnostic group	Psychology		Physics		Biology	
	Perc.	False belief	False photo	Balance	Innate potential	Illness
Preschoolers (N = 23)	.78	.87	1.00	.30	.13	.30
Autism (N = 19)	.26	.16	1.00	.47	.05	.32
Down's syndrome (N = 18)	.67	.28	.94	.67	.33	.39

For the domain of psychology there was no effect of task ( $F(1,57) = 3.48$ , n.s.), but there was a main effect of group ( $F(2,57) = 20.08$ ) and an interaction between task and group ( $F(2,57) = 3.65$ ,  $p < .05$ ). Exploring the main effect of group in more detail, one-way ANOVAs revealed significant group differences in both the false belief task ( $F(2,57) = 20.16$ ,  $p < .001$ ) and the perception task ( $F(2,57) = 7.338$ ,  $p < .001$ ). Bonferroni *post hoc*  $t$  tests showed that the preschoolers' performance on the false belief task was significantly better than the children with autism and children with DS ( $t(40) = 6.41$ ,  $p < .001$ ;  $t(39) = 4.54$ ,  $p < .001$ , respectively). With regard to the perception task,  $t$  tests showed that preschoolers and children with DS performed significantly better than children with autism ( $t(40) = 3.84$ ,  $p < .001$ ;  $t(35) = -2.62$ ,  $p < .05$ , respectively). The observed interaction effect was owing to children with DS performing significantly better on the perception task than the false belief task ( $t(17) = -2.72$ ,  $p < .01$ ), whereas preschool children and children with autism performed similarly on both tasks (see Table 2 for all means).

In relation to physics there was a main effect of task ( $F(1,57) = 98.52$ ,  $p < .001$ ) but no effect of group ( $F(2,57) = 1.19$ , n.s.) or interaction effect ( $F(2,57) = .68$ , n.s.). To explore the identified main effect in detail, analyses were performed on each participant group separately. *Post hoc* Bonferroni  $t$  tests comparing task scores showed significantly better performance on the false photo task than the balance scale task for all groups (preschoolers:  $t(22) = -7.09$ ,  $p < .001$ ; children with autism:  $t(18) = -4.47$ ,  $p < .001$ ; children with DS:  $t(17) = -5.83$ ,  $p < .001$ ; see Table 2 for means).

In the domain of biology there was a significant effect of task ( $F(1,57) = 5.72$ ,  $p < .05$ ) but again no effect of group ( $F(2,57) = 1.46$ , n.s.) or interaction effect ( $F(1,57) = .72$ , n.s.). There was an overall trend for all children to perform better on the innate potential task than the illness task (see Table 2 for means). However, this difference only reached significance in children with autism ( $t(18) = -2.54$ ,  $p < .001$ ) when groups were analysed separately (see Table 2 for means).

Results were also analysed non-parametrically to assess performance against that predicted by chance using a binomial distribution (the McNemar test; see Table 3). On both tasks pertaining to the domain of psychology, children with autism and children with DS performed at chance level. However, the preschoolers performed above the 33% level expected by chance on the false belief task ( $p < .001$ ) and the perception task ( $p < .001$ ). Children in all three groups performed at ceiling level on the false photo task well above the level predicted by chance guessing (all  $ps < .001$ ). No group displayed a better than chance performance on the tasks of innate potential and illness.

Table 3. Percentage of children in each group who passed each task

Diagnostic group	Psychology		Physics		Biology	
	Perc.	False belief	False photo	Balance	Innate potential	Illness
Preschoolers (N = 23)	78.3*	87.0*	100*	30.4	13.0	30.4
Autism (N = 19)	26.3	15.8	100*	47.4	5.3	31.6
Down's syndrome (N = 18)	66.7	27.8	94.4*	27.8	33.3	38.9

\* Denotes success above chance at  $p < .05$ , binomial test (note that chance level is 33%).

When the balance task was analysed according to the developmental trend highlighted by Siegler (1976), a clearer pattern emerged (see Table 4). Only children with DS differentiated between the two rules since the frequency of Rule II responses was highest in this group. The other two groups displayed a similar response pattern across both rules.

Table 4. Percentage (number) of children in each group applying different rules to answer the balance task

Diagnostic group	Rule I (weight only)		Rule II (weight & distance)		Wrong
Preschoolers (N = 23)	30.4 (7)		30.4 (7)		39.1 (9)
Autism (N = 19)	47.4 (9)		42.1 (8)		10.5 (2)
Down's syndrome (N = 18)	27.8 (5)		55.6 (10)		16.7 (3)

To explore in more depth the illness task data, initial responses were recoded taking into account the developmental trends identified by Kalish (1998) (see Table 5). Preschool children and children with autism were shown to judge illness causation as deterministic. Both these groups responded on the basis of the partially correct Rule I significantly more than predicted by chance guessing ( $p < .001$ ). However, the children with DS randomly selected a response, performing no different to that expected by chance.

Discussion

The present study found that preschool children, children with autism and children with DS demonstrated different levels of performance in the domain of psychology whereas understanding pertaining to the domains of physics and biology was similar across participant groups. As predicted, the preschoolers performed according to the 4-year-old level in all tasks. Children with autism revealed impaired performance in intuitive psychology. The finding that children with autism performed similarly to preschoolers (who had similar average VMA to children with autism) on intuitive physics tasks was taken as evidence that their understanding in this domain was intact although not superior. Contrary to prediction, the performance of children with autism on intuitive biology was not impaired. The pattern of results for children with DS was not as predicted as they performed similarly to preschoolers on all tasks apart from the

**Table 5.** Percentage (number) of children in each group applying different rules to answer the illness task

Diagnostic group	Rule I (deterministic)	Rule II (probabilistic)	Wrong
Preschoolers (N = 23)	73.9* (17)	13 (3)	13 (3)
Autism (N = 19)	68.4* (13)	5.3 (1)	26.3 (5)
Down's syndrome (N = 18)	38.9 (7)	33.3 (6)	27.8 (5)

\* Denotes success above chance at  $p < .05$ , binomial test (note that chance level is 66%).

false belief task, where they performed more poorly, and the illness task, where their performance was distributed randomly across possible responses.

The results of the intuitive psychology tasks confirm the findings of previous research showing that typically developing preschool children perform well on both the perception and false belief tasks. By contrast, children with autism performed consistently more poorly in the two tasks compared to preschoolers despite being of higher chronological age (CA) and similar VMA. A slightly different pattern of results was observed in relation to children with DS who performed well on the perception task but often failed the false belief task.

It is well documented that children with autism show poor performance on the false belief task (e.g. Baron-Cohen *et al.*, 1985; Leslie & Thaiss, 1992). However, relative failure on the perception task contrasts with other findings (Baron-Cohen, 1989b; Hobson, 1984; Leslie & Frith, 1988). It is possible that these slight discrepancies may have resulted from relatively high executive functioning demands of this task that required a participant to inhibit reference to their own perception while answering a question relating to another's perception. Executive functioning involves the ability to suppress a pre-potent but incorrect response while holding relevant information in working memory (Diamond, 1991; Pennington, *et al.*, 1997; Russell, 1996). Russell, Salinas, and Hill (1999) increased executive functioning demands in a 'desire' task and found this task adaptation reduced performance of children with autism to the same level as performance on a false belief task. Taken together, the results of the present study and those of Russell *et al.* (1999) suggest that executive functioning demands might play a role in the difficulty faced by children with autism on intuitive psychology tasks.

In contrast to children with autism and preschoolers, children with DS demonstrated differential levels of performance between the two psychology tasks. They showed a clear understanding of perceptual role taking, supporting the results of previous research (Baron-Cohen, 1989b). However, in contrast to the results of Baron-Cohen *et al.* (1985), they exhibited great difficulty understanding the standard false belief task. Indeed, despite requiring no linguistic demands to express responses, and participants having a higher mean VMA than the participants in Baron-Cohen *et al.*'s study (4.6 and 2.11 years, respectively), the performance of children with DS was nearly equivalent to that of children with autism. This poor performance had not been predicted and is difficult to reconcile with the findings of Baron-Cohen *et al.* (1985). Yet other studies have highlighted that participants with DS are impaired in tasks of intuitive psychology (Yirmiya *et al.*, 1996; Zelazo *et al.*, 1996) even though these studies included participants with a mean CA greater than 20 years. These conflicting results could be the product of cross-study differences in the range of severity of impairments within

groups of atypically developing children tested. Furthermore, task success requires groups of atypically developing children to comply with task demands and succeed, both cognitive ability and motivation to comply with task demands and succeed. Research has shown that children with DS may underperform in testing situations owing to motivational factors (Wishart, 1996b). In the present study, considerable effort was made to develop interesting and enjoyable task materials while maintaining the veracity of the test but perhaps the motivational demands of the false belief task were comparatively high for this group. Some authors have stated that standard intuitive psychology tasks can be employed to compare performance across clinical groups (Charman & Campbell, 1997; Hughes *et al.*, 2000), but more research is required to explore factors such as motivation that may confound findings of group differences in ability. Consequently, more work needs to be done to investigate intuitive psychological understanding in children with DS.

In relation to physics, there was a clear difference in performance between tasks across all three groups of children with performance on the false photo reaching ceiling level and scores on the balance being significantly lower. Taking each task in turn, the high performance scores on the false photo found in the present study are in contrast with previous work reporting much lower pass rates among typically developing preschoolers and children with autism (i.e. Leckham & Perner, 1991; Leslie & Thaiss, 1992; Peterson & Siegal, 1998; Zaitchik, 1990). The inclusion of non-verbal responses and the use of a small child-friendly camera may have facilitated performance in the present study. In addition, because most of the studies reporting lower levels of performance were conducted in the early 1990s, the superior performance on the false photo task reported here may reflect an increase in knowledge and experience of using a camera over the past 10 years.

A further issue is whether the false photo task is truly representative of the domain of physics. It might be possible for children to succeed on this task as a result of their procedural knowledge of using cameras rather than a deeper understanding of the nature or process of the representation. However, Peterson and Siegal (1998) suggest that the mechanistic nature of a camera draws attention to the encoding process and that the photograph provides a physical recording of the event, thus facilitating responses. It remains unclear, therefore, whether the task methodology of handling a camera is responsible for high success rates rather than conceptual knowledge of physics.

All groups in this study performed more poorly on the balance task than the false photo task and no significant group differences were identified. Furthermore, detailed examination of recorded responses showed that, for each group of participants, Rule II (the more developmentally advanced) was used at chance level. Despite these results, clear trends in the data were apparent. A higher percentage of children with autism than preschoolers passed the balance task overall and more often gave Rule II responses. This could be taken as evidence, together with performance on the false photo task, that understanding of physics was intact among children with autism when compared to preschoolers. However, children with autism were not found to have a superior understanding of physics as suggested by Baron-Cohen (1997, 2000) since more would have been expected to achieve Rule II understanding. Moreover, in order to investigate superiority in intuitive physics among children with autism, a typically developing CA match would be required and should be included in future research.

With regard to biology, there was a clear task effect across all three groups of participants with children performing better on the innate potential than the illness task as predicted. Performance rates for both the innate potential and the illness tasks



were similar across all groups. The similar performance of groups on these tasks is not in full agreement with Gopnik's (2001; Gopnik *et al.*, 2000) assertion that biological understanding may be impaired or less well developed in children with autism, but is in agreement with the findings of Peterson and Siegal (1997). To further investigate biology knowledge in atypically developing children, as with physics, it would be advantageous to include a CA match to assess the level of ability and the role of experience.

The findings in relation to innate potential resonate well with results showing no differences between children with autism and preschoolers on this task (Peterson & Siegal, 1997). However, the present study revealed lower performance scores across groups than those reported by Peterson and Siegal (1997) and the original version of the task (Gelman & Wellman, 1991). These discrepant results may be attributable to the materials used in this study. Great care was taken to follow the method of Peterson and Siegal (1997), but it is possible that minor differences could have influenced results. For example, in the present study the inclusion of a third response choice allowed for random guessing to be identified fully; consequently the present results may differ from previous work but may be a more accurate reflection of children's understanding.

Turning to the illness task, initial analyses showed that, overall, children performed at a lower level on this task than the innate potential task. More detailed analyses of the recorded data showed that preschool children and children with autism were deterministic in that they chose Rule 1 significantly more often than that expected by chance. However, children with DS produced an even response pattern across the three options that could indicate random guessing. Alternatively, the high CA of participating children with DS (thus more experience of illness) may lead to a greater number of participants in this group understanding the probabilistic nature of illness causation. However, a note of caution must be made. Perhaps it is possible that DS children may have interpreted the 'maybe' option in a manner differently from the other groups. Specifically, research has shown that children with DS often use avoidant learning strategies (Wishart, 1996a) and the 'maybe' option may have led these children to be reluctant to commit to a 'yes' or 'no' response. Thus these results may not show greater understanding but more a style of responding to the task by this group. A larger sample size and a more in-depth task such as the one used by Kalish (1998) should be used to investigate this issue further.

Taking the findings of the present study together, clear task differences and some group differences have been identified. This research confirms the recurrent finding that children with autism have a deficit in intuitive psychology, but extends past research in showing that performance of these children in intuitive physics especially, but also biology, is relatively unimpaired compared to typically developing preschool children. This study highlights the need for caution when ascribing domain-specific knowledge to children because of the difficulty in developing equivalent tasks in different domains and equating task demands across participant groups. Comparing performance across domains, especially in atypically developing children, is a difficult endeavour in view of both the lack of homogeneity within clinical groupings and the differing diagnostic criteria applied within and across nations. However, to gain better understanding of children's domain-specific knowledge, its development and neurological bases, we need to continue to investigate possible links between these domains in both typically developing children and clinical groups.

## References

- Atran, S. (1999). Intra Maya folkbiological taxonomy: Cognitive universals and cultural particulars. In D. L. Medin & S. Atran (Eds.), *Folkbiology* (pp. 119–204). Cambridge, MA: MIT Press.
- Ballingcon, R. (2000). How do infants learn about the physical world? In D. Mair & A. Slater (Eds.), *Infant development: The essential readings* (pp. 195–212). Oxford: Blackwell.
- Baron-Cohen, S. (1989a). Are autistic children 'behaviourists'? An examination of their mental-physical and appearance-reality distinctions. *Journal of Autism and Developmental Disorders*, 19, 579–600.
- Baron-Cohen, S. (1989b). Perceptual role taking and protodeclarative pointing in autism. *British Journal of Developmental Psychology*, 7, 113–127.
- Baron-Cohen, S. (1991). Do people with autism understand what causes emotion? *Child Development*, 62, 385–395.
- Baron-Cohen, S. (1997). Are children with autism superior at folk physics? In H. Wellman & K. Inagaki (Eds.), *New Directions for Child Development Series No. 75: The emergence of core domains of thought: Children's reasoning about physical, psychological and biological phenomena* (pp. 45–54). San Francisco, CA: Jossey-Bass.
- Baron-Cohen, S. (2000). Autism: Deficits in folk psychology exist alongside superiority in folk physics. In S. Baron-Cohen, H. Tager-Flusberg, & D. J. Cohen (Eds.), *Understanding other minds: Perspectives from developmental cognitive neuroscience* (pp. 73–83). Oxford: Oxford University Press.
- Baron-Cohen, S., Leslie, A. M., & Frith, U. (1985). Does the autistic child have a 'theory of mind'? *Cognition*, 21, 37–46.
- Baron-Cohen, S., Spitz, A., & Cross, P. (1993). Can children with autism recognise surprise? *Cognition and Emotion*, 7, 507–516.
- Baron-Cohen, S., & Wheelwright, S. (1999). 'Obsessions' in children with autism or Asperger Syndrome: A content analysis in terms of core domains of cognition. *British Journal of Psychiatry*, 175, 484–490.
- Baron-Cohen, S., Wheelwright, S., Stone, C., Bolton, P., & Goodyer, I. (1997). Is there a link between engineering and autism? *Autism: An International Journal of Research and Practice*, 1, 153–163.
- Carey, S. (1985). *Conceptual change in childhood*. Cambridge, MA: MIT Press.
- Carey, S. (2001, April). *Conceptual change in three core domains of thought*. Society for Research in Child Development, biennial meeting, Minneapolis.
- Carey, S., & Spelke, E. (1994). Domain-specific knowledge and conceptual change. In L. A. Hirschfeld & S. A. Gelman (Eds.), *Mapping the mind: Domain specificity in cognition and culture* (pp. 169–200). Cambridge: Cambridge University Press.
- Charman, T., & Campbell, A. (1997). Reliability of theory of mind task performance by individuals with a learning disability. *Journal of Child Psychology and Psychiatry*, 38, 725–730.
- Diamond, A. (1991). Neuropsychological insights into the meaning of object concept development. In S. Carey & S. A. Gelman (Eds.), *The epigenesis of mind: Essays on biology and knowledge* (pp. 67–110). Hillsdale, NJ: Erlbaum.
- Dunn, L. M., Dunn, L. M., Whetton, C., & Burley, J. (1997). *The British picture vocabulary scale II*. Windsor: NFER-Nelson.
- Fodor, J. A. (1983). *The modularity of mind: An essay on faculty psychology*. Cambridge, MA: MIT Press.
- Freeman, S. F. N., & Hodapp, R. M. (2000). Educating children with Down Syndrome: Linking behavioural characteristics to promising intervention strategies. *Down Syndrome Quarterly*, 5, 1–9.
- Frith, U. (1989). *Autism: Explaining the enigma*. Oxford: Basil Blackwell.
- Frith, U., & Happé, F. (1994). Autism: Beyond 'theory of mind'. *Cognition*, 50, 115–132.
- Gelman, S. A., & Wellman, H. M. (1991). Insides and essences: Early understandings of the non-obvious. *Cognition*, 38, 213–244.

- Gopnik, A. (2001, April). *Do children with autism have folkbiology?* Society for Research in Child Development, biennial meeting, Minneapolis.
- Gopnik, A., Caspi, A., & Meltzoff, A. N. (2000). Early theories of mind: What the theory theory can tell us about autism. In S. Baron-Cohen, H. Tager-Flusberg, & D. J. Cohen, (Eds.), *Understanding other minds: Perspectives from developmental cognitive neuroscience* (pp. 50-73). Oxford: Oxford University Press.
- Gopnik, A., & Meltzoff, A. N. (1997). *Words, thoughts, and theories*. Cambridge, MA: MIT Press.
- Gunter, M. R., & Maratsos, M. (Eds.) (1992). *The Minnesota symposia on Child Psychology: Vol. 25 Modularity and constraints in language and cognition*. Hillsdale, NJ: Erlbaum.
- Heyman, G. D., & Dweck, C. S. (1998). Children's thinking about traits: Implications for judgments of self and others. *Child Development*, 69, 391-403.
- Hirschfeld, L. A., & Gelman, S. A. (1994). Toward a topography of mind: An introduction to domain specificity. In L. A. Hirschfeld & S. A. Gelman (Eds.), *Mapping the mind: Domain specificity in cognition and culture*, (pp. 3-35). Cambridge: Cambridge University Press.
- Hobson, R. P. (1984). Early childhood autism and the question of egocentrism. *Journal of Autism and Developmental Disorders*, 14, 85-104.
- Hobson, R. P. (1986). The autistic child's appraisal of expressions of emotion: A further study. *Journal of Child Psychology and Psychiatry*, 27, 321-342.
- Hughes, C., Adam, A., Happe, F., Jackson, J., Taylor, A., & Caspi, A. (2000). Good test-retest reliability for standard and advanced false belief tasks across a wide range of abilities. *Journal of Child Psychology and Psychiatry*, 41, 483-490.
- Johnson, S. C., & Carey, S. (1998). Knowledge enrichment and conceptual change in folkbiology: Evidence from William's syndrome. *Cognitive Psychology*, 37, 156-200.
- Kalish, C. W. (1998). Young children's predictions of illness: Failure to recognise probabilistic causation. *British Journal of Developmental Psychology*, 34, 1046-1058.
- Kalish, C. W. (1999). What young children's understanding of contamination and contagion tells us about their concepts of illness. In M. Siegal & C. C. Petersen (Eds.), *Children's understanding of biology and health* (pp. 99-131). Cambridge: Cambridge University Press.
- Karmiloff-Smith, A. (1992). *Beyond modularity: A developmental perspective on cognitive science*. Cambridge, MA: MIT Press.
- Keil, F. C. (1999). Cognition, content, and development. In M. Bennett (Ed.), *Developmental psychology: Achievements and prospects* (pp. 165-183). Philadelphia, PA: Psychology Press.
- Leckman, S. R., & Perner, J. (1991). Does the autistic child have a representational deficit? *Cognition*, 40, 203-218.
- Leslie, A. M., & Frith, U. (1998). Autistic children's understanding of seeing, knowing, and believing. *British Journal of Developmental Psychology*, 6, 315-324.
- Leslie, A. M., & Thaiss, L. (1992). Domain specificity in conceptual development: Neuropsychological evidence from autism. *Cognition*, 43, 225-251.
- McGarrigle, J., & Donaldson, M. (1974). Conservation accidents. *Cognition*, 3, 341-350.
- McGregor, E., Whiten, A., & Blackburn, P. (1998). Teaching theory of mind by highlighting intention and illustrating thoughts. *British Journal of Developmental Psychology*, 16, 281-300.
- Mundy, P. (1997). Joint attention and social-emotional approach behavior in children with autism. *Development and Psychopathology*, 7, 63-82.
- Mundy, P., & Crowson, M. (1997). Joint-attention and early social communication: Implications for research on intervention with autism. *Journal of Autism and Developmental Disorders*, 27(6), 63-82.
- Mundy, P., & Sigman, M. (1989). The theoretical implications of joint attention deficits in autism. *Development and Psychopathology*, 1, 173-183.
- Pauen, S. (1996). Children's reasoning about the interaction of forces. *Child Development*, 67, 2728-2742.
- Pennington, B. F., Rogers, S. J., Bennetto, L., Griffith, E. M., Reed, D. T., & Shyu, V. (1997). Validity tests of the executive dysfunction hypothesis of autism. In J. Russell (Ed.), *Autism as an executive disorder* (pp. 143-178). Oxford: Oxford University Press.
- Perner, J., Frith, U., Leslie, A. M., & Leckman, S. R. (1989). Exploration of the autistic child's theory of mind: Knowledge, belief and communication. *Child Development*, 60, 689-700.
- Petersen, C. C., & Siegal, M. (1997). Domain specificity and everyday biological, physical, and psychological thinking in normal, autistic, and deaf children. In H. M. Wellman & K. Inagaki (Eds.), *New Directions for Child Development* Series No. 75: *The emergence of core domains of thought: Children's reasoning about physical, psychological and biological phenomena* (pp. 55-71). San Francisco, CA: Jossey-Bass.
- Petersen, C. C., & Siegal, M. (1998). Changing focus on the representational mind: Deaf, autistic and normal children's concepts of false photos, false drawings and false beliefs. *British Journal of Developmental Psychology*, 16, 301-320.
- Russell, J. (Ed.) (1998). *Autism as an executive disorder*. Oxford: Oxford University Press.
- Russell, J., Mauthner, N., Sharpe, S., & Tidswell, T. (1991). The 'windows' task as a measure of strategic deception in pre-schoolers and autistic subjects. *British Journal of Developmental Psychology*, 9, 331-349.
- Russell, J., Saltmarsh, R., & Hill, E. (1999). What do executive factors contribute to the failure on false belief tasks by children with autism? *Journal of Child Psychology and Psychiatry*, 40, 859-868.
- Siegel, R. (1976). Three aspects of cognitive development. *Cognitive Psychology*, 8, 481-520.
- Slaughter, V., & Gopnik, A. (1996). Conceptual coherence in the child's theory of mind: Training children to understand belief. *Child Development*, 67, 2967-2988.
- Speke, E. S., Brethling, K., Macomber, J., & Jacobson, K. (1992). Origins of knowledge. *Psychological Review*, 99, 605-632.
- Springer, K. (1999). How a naive theory of biology is acquired. In M. Siegal & C. C. Petersen (Eds.), *Children's understanding of biology and health* (pp. 45-71). Cambridge: Cambridge University Press.
- Tager-Flusberg, H., & Sullivan, K. (2000). A componential view of theory of mind: Evidence from William's syndrome. *Cognition*, 76(1), 58-89.
- Wellman, H. M., & Gelman, S. A. (1992). Cognitive development: Foundational theories and core domains. *Annual Review of Psychology*, 43, 337-375.
- Wellman, H. M., Hickling, A. K., & Shult, C. A. (1997). Young children's psychological, physical and biological explanations of human behavior. In H. M. Wellman & K. Inagaki (Eds.), *New directions for child development* Series No. 75: *The emergence of core domains of thought: Children's reasoning about physical, psychological and biological phenomena* (pp. 7-26). San Francisco, CA: Jossey-Bass.
- Wellman, H. M., Hickling, A. K., & Shult, C. A. (2000). Young children's psychological, physical and biological explanations. In K. Lee (Ed.), *Childhood cognitive development: The essential readings* (pp. 267-288). Oxford: Blackwell.
- Wellman, H. M., & Inagaki, K. (1997). *New Directions for Child Development* Series No. 75: *The emergence of core domains of thought: Children's reasoning about physical, psychological and biological phenomena*. San Francisco, CA: Jossey-Bass.
- Wellman, H. M., & Lagatuta, K. H. (2000). Developing understandings of mind. In S. Baron-Cohen, H. Tager-Flusberg, & D. J. Cohen (Eds.), *Understanding other minds: Perspectives from developmental cognitive neuroscience* (2nd ed., pp. 21-44). Oxford: Oxford University Press.
- Williams, J. M., & Bunne, L. M. (2002). Children's concept of illness: An intervention to improve knowledge. *British Journal of Health Psychology*, 7, 129-147.
- Williams, J. M., & Toimie, A. (2000). Conceptual change in biology: Group interaction and the understanding of inheritance. *British Journal of Developmental Psychology*, 18, 625-649.
- Wishart, J. G. (1996a). Avoidant learning styles and cognitive development in young children with Down's syndrome. In B. Stratford & P. Gunn (Eds.), *New approaches to Down's syndrome* (pp. 173-205). London: Casserz.
- Wishart, J. G. (1996b). Learning in young children with Down's syndrome: Developmental trends. In J. A. Rondal, J. Pereira, L. Nadel, & A. Comblan (Eds.), *Down's syndrome: Psychological, psychobiological and socio-educational perspectives* (pp. 81-96). London: Whurr.

- Wishart, J. G. (1999). Learning and development in children with Down's syndrome. In A. Slater & D. Muir (Eds.), *The Blackwell Reader in Developmental Psychology* (pp. 493-509). Oxford: Blackwell.
- Yirmiya, N., Solomonica-Levi, D., Shulman, C., & Pilowsky, T. (1996). Theory of mind abilities in individuals with autism, Down syndrome and mental retardation of unknown etiology: The role of age and intelligence. *Journal of Child Psychology and Psychiatry* 37, 1003-1014.
- Zaitchik, D. (1990). When representation conflicts with reality: The preschooler's problem with false belief and false photographs. *Cognition*, 35, 41-68.
- Zelazo, P. D., Burack, J. A., Benedetto, E., & Frye, D. (1996). Theory of mind and rule use in individuals with Down syndrome: A test of the uniqueness and specificity claims. *Journal of Child Psychology and Psychiatry*, 37, 479-484.

Received 25 August 2000; revised version received 21 November 2001

# Intuitive psychology and physics among children with autism and typically developing children

LYNNE BINNIE *University of Edinburgh, Scotland, UK*

autism © 2002  
SAGE Publications  
and The National  
Autistic Society  
Vol 6(4) 397-417: 029093  
1362-3613(200212)6:4



**KEY WORDS**  
autism;  
domain  
specificity;  
intuitive  
physics;  
intuitive  
psychology

**ABSTRACT** Many studies have documented poor understanding of intuitive psychology among children with autism; however, few have investigated claims of superior understanding of intuitive physics said to be evident in this group. This study aimed to investigate the reported differential preference of intuitive psychology and intuitive physics among children with autism by employing three tasks each with a psychological and a physical condition. In order to gain a detailed developmental picture the study compared children with autism, a CA match group, and typically developing preschoolers, 7-year-olds and 10-year-olds. Results demonstrated that children with autism preferred to employ physical causality when reasoning about novel physical and psychological events. Furthermore, their performance on a multiple-choice task confirmed their impairment in intuitive psychology whilst highlighting a superior ability to reason about physical phenomena in relation to all other comparison groups. Theoretical implications of this potential cognitive strength are discussed.

**ADDRESS** Correspondence to DR JOANNE WILLIAMS, *Lecturer in Psychology, Faculty of Education, St Johns Lane, Holyrood Road, Edinburgh EH8 8AQ, UK. e-mail: jo.williams@ed.ac.uk*

## Introduction

In his seminal paper Kanner (1943) noted that the child with autism demonstrates excellent, purposeful and intelligent relations to objects whilst exhibiting virtually no relations to people. Subsequent work in this area charts a similar preference for physical phenomena among children with autism. For example, Wing (1969) found a greater attachment to objects in children with autism than in other diagnostic groups. Furthermore, the clinical literature describes hundreds of cases of children with autism who are obsessed with machines and other physical systems

## AUTISM 6(4)

(Baron-Cohen et al., in press). Family studies have also highlighted that fathers and grandfathers of children with autistic spectrum disorder are over-represented in occupations with a strong physical component, such as engineering (Baron-Cohen and Hammer, 1997). Surprisingly, however, only a small number of direct comparisons has been made between the difficulties children with autism have in relating to people and the relative ease with which they interact with physical objects (Baron-Cohen, 1997; 2000). Within the cognitive development literature this potential dissociation has been characterized as a distinction between intuitive psychology and intuitive physics. This differentiation can be related to the theory that cognition develops in a domain-specific fashion.

## Domain specificity: the core domains of psychology and physics

The study reported in this article proposes to investigate two domains of knowledge, namely psychology and physics. The former is concerned with persons and their mental life and the latter focuses on physical objects and their movement (Wellman and Inagaki, 1997). Domains are characterized as intuitive, and as involving a set of causal explanatory mechanisms (e.g. principles or theories), a set of ontological commitments (i.e. rules concerning application of mechanisms) and a set of phenomena to which mechanisms are applied (i.e. ontology) (Binnie and Williams, in press; Murphy and Medin, 1985; Wellman, 1990). It must be noted that this study is not concerned with the precise cognitive structure of intuitive psychology or intuitive physics. It is sufficient to state that they are both 'core domains of cognition' that in typically developing children are established very early in childhood (Wellman and Gelman, 1992; Wellman and Inagaki, 1997; Wellman et al., 2000). Further, accumulating work has reported that children with differing learning abilities often show uneven cognitive development. These two strands of work have led some researchers to conclude that much of cognition operates in a domain-specific fashion (Gunnar and Maratos, 1992). In short, 'domain specificity' proposes that one domain of knowledge will develop somewhat independently from another and will continually engage specific constraints. These constraints will render the domain specialized in acquiring and organizing information.

Sperber et al. (1995) propose that 'causal cognition' can be broadly divided into psychological and physical causality. Wellman et al. (2000) suggest that children have a preoccupation with the causes and explanations of psychological and physical phenomena and that this may be a very early contributor to cognitive development. Leslie (1994) goes further and



suggests that children's attention to these two types of knowledge systems is a result of the presence of two innate modules. The 'theory of body mechanism' (Toby) accounts for the infant's rapid acquisition of knowledge about the non-intentional mechanical properties of agents and subsequent events (i.e. physics). By contrast, the 'theory of mind mechanism' (ToMM, system 1 and system 2) is concerned with the intentional properties of agents (i.e. psychology).

### **Intuitive psychology and physics: typical development**

It is thought that concepts within the domains of intuitive psychology and physics comprise fundamental implicit (and possibly innate) principles. These principles are often evident in early infancy but also encompass developmentally advanced concepts that emerge in later childhood.

Whilst there is no consensus over the exact concepts that belong to the domains of psychology and physics it is commonly agreed that intuitive psychology involves reasoning about persons and their mental life. This domain is utilized during interactions with others and allows feelings, desires, motivations and intentions to be taken into account when reasoning about human behaviour. To reason about these concepts effectively we must assume that the mind exists, the mind consists of various mental states and processes, and there are various causal links between an individual's mind, external environments and actions (Lee and Horner, 1999). In order to arrive at these conclusions intuitive psychology encompasses basic communication skills present in infancy such as shared attention (Mundy and Crowson, 1997) and the ability to imitate facial expressions (Meltzoff and Moore, 1977). It also includes more advanced concepts present in typical development by the age of 4 years such as being able to attribute mental states to oneself and others (Leslie, 1987), having an appreciation that seeing leads to knowing (Pruitt and Bryant, 1990) and understanding emotional causality (Harris et al., 1989). As development proceeds more complex concepts, such as having an appreciation of personality traits, emerge (Heyman and Dweck, 1998).

In contrast, the literature on intuitive physics is very piecemeal, despite many physical concepts having been investigated (see Howe, 1998). This study will focus on potential candidates for fundamental physical knowledge surrounding objects, their movement and their characteristics (such as weight). Intuitive physics makes its appearance in children's knowledge of solid cohesive physical objects and the causal regularities that they exhibit. The 'object concept' has been identified as a core constituent of this domain and involves fundamental knowledge found in infants as young as 3-4 months old (Baillargeon et al., 1985). By extension, this domain

involves reasoning about 'object dynamics' and the physical causes of non-agent initiated events. This includes the ability of 4-month-old infants to appreciate that inanimate objects move in accordance with the principles of cohesion, continuity and contact (Spelke et al., 1995). More advanced concepts within this domain include the notion that a cause will produce an effect by transmitting a force or restraint to it, or a set of forces will cause trajectories, gravity, accelerations and so on (Wellman and Gelman, 1992). The ability to reason about these more advanced object related concepts becomes apparent between the ages of 3 and 4 years (Das Gupta and Bryant, 1989; Gelman et al., 1980). A theoretical understanding of motion is thought to be present by the age of 7-12 years (Kaiser et al., 1986).

Concepts such as object size, weight and density are thought to be contained in a theoretical system by the age of 3-4 years (Smith et al., 1985). Children's understanding of these concepts has been considered in terms of intuitive 'mechanics' encompassing ideas about how mechanical/physical things work (Baron-Cohen et al., in press; Dienes, 1998; Piaget, 1930). For example, Siegler (1976) investigated children's understanding about the workings of a balance scale. He asked children which arm of the scale would descend when one variable (weight or distance) was held constant and the other varied. The majority of the 5- to 6-year-olds considered the dimensions of weight and distance separately (i.e. the arm with the most weights would go down). Children aged 9-10 years took into account distance information only when each arm held the same number of weights. Children aged 13-14 considered both variables but only when the two did not conflict. Only by the age of 16-17 could participants integrate weight and distance information fully.

### **Intuitive psychology and physics: children with autism**

Although it may be the case that typically developing children can employ specific reasoning systems in relation to psychological and physical phenomena, a large body of research carried out on children with autism has shown that they lack an understanding of psychology. Children with autism find it difficult to reason appropriately about a wide range of psychological phenomena, including basic infant social cognition principles such as shared attention (Dawson et al., 1998) as well as more developmentally advanced concepts such as false belief (Baron-Cohen et al., 1985). In contrast, accumulating work shows that children with autism have a relatively intact understanding of physical phenomena (Baron-Cohen, 2000). However a recent study indicates that children with autism do have difficulties relating to objects and that their interactions with

objects differ qualitatively from their typically developing age-matched peers (Williams et al., 1999). Thus, they manipulate objects in an unusual way, and prefer to explore and inspect them in close detail, often looking at an object, or a single part of it, for an extended period of time. Consequently, the authors suggest that children with autism may be impaired in this area. However, an alternative explanation is that children with autism are profoundly interested in objects and wish to understand how they operate. Support for this idea can be found in a content analysis that has revealed that many of the obsessional interests among children with autism cluster in the domain of physics (Baron-Cohen and Wheelwright, 1999).

The tendency of children with autism to differentiate between intuitive psychology and physics is clearly evident when comparing performance on two tasks that are similar in structure yet represent different domains of knowledge. This was first noted by Leekham and Perner (1991) who administered a 'false photo task' (Zaitchik, 1990) to children with autism. This task was designed to be similar in structure to the false belief task (Wimmer and Perner, 1983) but involved physical rather than mental representations. In the false photo task a camera records a scene, then an object is moved from position A to B. Findings from this study and subsequent replications (e.g. Binnie and Williams, *in press*; Petersen and Siegal, 1998) have shown that children with autism correctly identify the object that will appear in the photo. Thus, they have an intact ability to understand the nature of physical representations created by a camera, in stark contrast to their poor performance on tasks of false belief. This paradigm involves a person viewing a scene then leaving; whilst they are absent an object is moved from position A to B. Children with autism consistently predict that on return the person will look for the object in its present (but wrong) location. These studies show that children with autism have an understanding of intuitive physics that is far more advanced than their intuitive psychology.

An early study employed a picture sequencing paradigm to compare intuitive psychology and intuitive physics. When instructed to arrange pictures into a pre-determined sequence, children with autism were shown to perform poorly on intentional stories that required an understanding of a character's mental state. On the other hand, they performed significantly better than 4-year-old children and a group of children with Down's syndrome at sequencing physical causal sequences. Further, the children with autism were also more likely to produce descriptive utterances in the physical condition in contrast to the intentional one (Baron-Cohen et al., 1986).

More evidence that children with autism show a preference for reasoning in terms of intuitive physics has been shown in a recent study concerning different types of object movement (Bowler and Thommen, 2000).

401

## AUTISM 6(4)

Initial findings indicated that children with autism could distinguish psychological and physical entities by correctly differentiating patterns of movement that characterize agents (animate) and non-agents (inanimate). However, when this was investigated in more depth, children with autism were shown to have difficulty in describing the actions of two animate agents when their interaction did not involve contact. They could reason appropriately about interactions that involved physical contact. A new interpretation of these results is that even when reasoning about animate agents, children with autism may employ their physical reasoning system and when this cannot be employed (as in the no contact condition) they find any subsequent interpretation difficult.

Some phenomena have characteristics and functions that relate to both psychological and physical phenomena, a prime example being the brain. Work has shown that typically developing 4-year-olds attribute mental functions to the brain (e.g. thinking, dreaming). Only much later (sometimes not even by 11 years) do children fully understand that the brain is also necessary for physical behaviour (e.g. walking, running) (Johnson and Wellman, 1982). Baron-Cohen (1989) extended this work by asking children with autism what they understood about the brain. He found that they were more likely to report physical functions pertaining to the brain in contrast to typically developing 5-year-olds and a developmentally delayed group, who both preferred to elicit mentalistic functions (the most common one being 'thinking'). By referring to the brain in terms of physical attributes, the authors suggested that children with autism were in fact giving more complex answers than the other two groups. On this basis it was suggested that they have a precocious understanding of physical phenomena; however, they did have a higher mental age (MA) than the comparison groups.

In a direct comparison study Baron-Cohen et al. (*in press*) revealed a striking contrast between understanding of intuitive psychology and physics in children diagnosed with Asperger syndrome. Asperger syndrome, albeit very similar in nature to autism, does not involve linguistic or cognitive delays (American Psychiatric Association (APA), 1994; World Health Organization (WHO), 1992); therefore individuals diagnosed with this condition usually function within the normal range of abilities (Baron-Cohen and Bolton, 1993). The psychology task involved participants being shown photographs of the eye region before being asked to select, from a choice of four emotions, the one that the person is thinking or feeling (adapted from Baron-Cohen et al., 1997). The physics task involved 20 multiple-choice questions depicting the everyday physical causal world (such as how things work, motion and balance). Compared to younger typically developing children (hence lower MA), those with

402

Asperger syndrome were impaired in basic psychological understanding. However, in comparison to a chronological age (CA) comparison group (i.e. similar MA) they demonstrated superior performance when reasoning about physical phenomena. This study appears to offer strength to the claim that children with an autistic spectrum disorder show superior understanding in the domain of physics. However, it must be noted that the intuitive psychology and physics tasks in this study were not similar in structure or procedure.

Accumulating work suggests that children with autism have a predisposition to relate to physical phenomena as a result of their cognitive phenotype. Nevertheless, Baron-Cohen et al. (in press) point out that 'the brain basis of folk physics' remains unclear. More detailed research is needed to support these initial findings concerning physics knowledge among children with autism before the physiological and structural bases of these abilities can be determined.

### The present study

This study employed three tasks each with an intuitive psychology and intuitive physics condition. Group differences across conditions in each task were examined in three groups of typically developing children, children with autism and a CA match group. The CA match group was included to provide a direct comparison group for the children with autism in terms of their duration of experience of the physical and psychological worlds. Groups of typically developing preschoolers, 7- and 10-year-olds were included to provide baseline normative developmental data on the newly developed tasks. Together these comparison groups would allow a full investigation into claims that children with autism have superior reasoning for physical phenomena. The picture sequencing task gave participants a fixed choice of two options. It was predicted that children with autism would be more likely to respond with the intuitive physical rather than the psychological option. The categorization task aimed to observe how children would categorize intuitive psychological and physical phenomena. It was expected that children with autism would choose superficial features to categorize psychological items but physical features to categorize physical items. Performance on the multiple-choice task was expected to show children with autism performing poorest on items involving intuitive psychology. However, they were expected to perform at least similarly or indeed better than their CA match group, preschoolers and 7-year-olds on tasks of intuitive physics. The 10-year-old children were expected to perform better than all comparison groups on both conditions.

403

## AUTISM 6(4)

### Method

#### Participants

The 94 participants in this study comprised 17 preschoolers, 18 7-year-olds, 17 10-year-olds, 21 children diagnosed with autism according to DSM-IV (APA, 1994) or ICD-10 (WHO, 1992) criteria, and a group of 21 typically developing children matched to the children with autism according to CA and gender. The typically developing children were recruited from one nursery and one state primary school in Edinburgh. All children with autism were being educated within a language unit in one of four mainstream state schools in Edinburgh. The receptive vocabulary of children with autism was assessed using the BPVS-II (Dunn et al., 1997) to ensure that they had an age equivalent of at least 4.5 years, the minimum necessary to understand task instructions. In addition, all participants were administered the standard performance subtest of the WPPSI-R UK (Wechsler, 1990) or the WISC-III UK (Wechsler, 1992) as a measure of performance IQ (PIQ). Table 1 details the sample characteristics.

### Task materials

#### Picture sequencing task

This task compared physical and psychological causation via a picture sequencing task modified from the one used by Baron-Cohen et al. (1986). The task included eight picture sequence trials comprising two conditions: four manmade artefacts (e.g. car) and four natural artefacts (e.g. flower). These two categories were chosen to reflect a living versus non-living distinction, the former being more psychologically loaded in contrast to the latter which is more associated with physical attributes (see Table 2). For each picture sequence trial participants were presented with the first and last picture of a causal sequence. They were then asked to choose, from two

**Table 1** Diagnostic groups: number (N), mean chronological age (CA), mean performance IQ (PIQ) and mean receptive vocabulary (BPVS-II)

Diagnostic group	N	CA (years/months)	Range	PIQ <sup>a</sup>	Range	BPVS
Autism	21	6:3	5:5-10:2	90	61-119	6.5 (4.5-9.0)
CA match	21	6:3	5:5-10:2	102	90-130	
Preschoolers	17	4:7	4:4-4:11	101	86-109	
7-year-olds	18	7:4	7:1-7:11	108	95-140	
10-year-olds	17	10:3	10:1-10:11	99	77-112	

<sup>a</sup> WPPSI-R or WISC-III.

404



pictures depicting different causal mechanisms, the one that would best explain the sequence of events. One picture depicted a physical causal mechanism and the other depicted psychological causation.

The picture sequence trials were presented randomly. The standard procedure for each trial involved the experimenter placing the first and last picture of the causal sequence onto a Velcro board leaving a suitable gap for the intermediate picture. Participants were told that 'this is the first picture in the story [the experimenter points to the first picture on the Velcro board] and this is the last picture [the experimenter points to the last picture]'. The two intermediate pictures were placed randomly on the table beside the Velcro board, avoiding any positional cues that might lead to a systematic bias in responding. Children were then instructed to 'look at these pictures' (the experimenter points to the two intermediate pictures, being careful to avoid any cues that might influence the participant's choice) and were asked 'which one will go in the middle to tell the best story?' They were then invited to attach their choice to the Velcro board.

Responses to each condition were scored according to the type of causation chosen on a scale from 0 (all items completed on basis of physical causal picture) to 4 (all items completed on basis of psychological causal picture).

**Table 2** The content of the eight stories in the picture sequencing task

First picture	Psychological	Physical	Last picture
<i>Mannmade artefacts:</i>			
Bulb on	Hand turning switch off	Element breaking	Bulb off
Car at top of hill	Hand pushing car	Car pushing car	Car at bottom of hill
Tap of running water	Hand turning off tap	Burst pipe	Tap of drips of water
Floating balloon	Hand pricking balloon	Tree pricking balloon	Burst balloon
<i>Natural artefacts:</i>			
Apple on tree	Hand picking apple off	Apple falling off	Apple on ground
Flower standing	Hand cutting flower	Flower falling over (wind)	Flower stem cut
Tree standing	Hand cutting tree	Lightning hitting tree	Tree cut into two
Rock at top of hill	Hand pushing rock	Wind pushing rock	Rock at bottom of hill

405

#### AUTISM 6(4)

##### Categorization task

Employing similar methodology to previous categorization studies (e.g. Savitsky and Izard, 1970; Weeks and Hobson, 1987) this task comprised a psychological and a physical condition. In order to examine the degree to which fundamental features of faces (i.e. emotional expression) and fundamental physical laws (e.g. gravity) are salient for participants, these features were combined with more superficial features (that did not relate to core psychological or physical principles).

There were four trials for the psychological condition and four trials for the physical condition. Every trial consisted of eight cards that varied in terms of the combinations of fundamental features and superficial features. The fundamental features in the psychological condition comprised four emotional expressions (i.e. happy or neutral, sad or neutral, angry or neutral, surprised or neutral; expressions were taken from Howlin et al., 1999). The fundamental features in the physical condition comprised cards depicting one of four physical laws (i.e. floating or sinking, gravity or no gravity, balance or imbalance and object contact or no contact). In both conditions the superficial features were colour (two colours in each trial). By presenting these combinations of features children could categorize cards in terms of either fundamental laws (psychology or physics) or superficial features (i.e. colour).

All trials followed a standard procedure. A Velcro board was placed in front of the participant with a piece of white tape running down the middle. Participants were presented with an introductory task comprising eight cards (four cards depicted a circle and four a square). They were asked to notice and remember a way in which the cards differed from each other and were initially asked to sort the cards into two groups and then place the card groups on either side of the Velcro board. In line with Weeks and Hobson (1987) this introductory task was designed to test whether the participants could sort cards as well as allowing the children with autism to assimilate the task procedure. Following this, the participants were administered the experimental task. For each randomly administered trial the cards were placed in front of the children in a random pile. The children were then asked to follow the same procedure as for the introductory task. Responses to each condition (psychology and physics) were scored according to how categorization was completed on a scale from 0 (all trials completed according to superficial features) to 4 (all trials completed according to fundamental features).

##### Multiple-choice task

Participants were presented with a workbook comprising 12 questions concerning intuitive physics knowledge and 12 concerning intuitive

406



psychological knowledge. Each condition comprised two classes of phenomena that subsumed two further specific principles. In relation to physics the two phenomena were 'object motion' (three questions on gravity, Kim and Spelke, 1999; and three questions on trajectory, Kaiser et al., 1985), and 'how things work' (three questions on mechanics, Metz, 1985; and three questions on balance, Siegler, 1976). With regard to psychology the two phenomena were 'emotion' (three questions on schematic face recognition and three questions on desire-based emotions, Howlin et al., 1999) and 'belief' (three questions on simple perspective taking, and three questions on 'saying leads to knowing', Howlin et al., 1999) (see Table 3). Each subcategory was designed to investigate increasingly sophisticated levels of understanding in order to accommodate the range of ability in the participant groups and to avoid possible ceiling effects (e.g. for balance tasks the variables considered were weight, distance and weight combined with distance).

The experimenter read out each question from the workbook and subsequently asked the participants to choose the best answer from three illustrations. Participants were instructed to 'tick the box under the picture that you think best answers the question'. Questions were presented in a standard sequence to participants and correct responses were summed to give a score out of 12 for each condition.

### Procedure

The three tasks were administered randomly to participants in a quiet room with no single session taking longer than 35 minutes. In accordance with this time constraint IQ was often assessed during two sessions. All the experimental tasks were designed to be of fixed choice requiring limited verbal instructions. No verbal response was needed and instead participants were simply required to place the picture(s) that best answered the question onto a Velcro board. This procedure served a number of purposes: (1) It

**Table 3** Classes of phenomena in each condition of the multiple-choice task

Condition	Category	Subcategory
Physics	Object motion	Gravity Trajectory Mechanics
	How things work	Balance
Psychology	Emotion	Schematic face recognition Desire-based emotions
	Belief	Simple perspective taking Saying leads to knowing

407

### AUTISM 6(4)

avoided the children with autism being disadvantaged owing to their relatively poor language abilities; (2) it focused participants' attention on the task; and (3) it allowed the experimenter correctly and clearly to identify the participant's answer(s).

Participants were allowed to complete the tasks at their own pace with the experimenter recording their choices. If a response was not forthcoming the experimenter repeated the question/instructions one more time. Positive feedback was given after every task, e.g. 'that's good, well done'.

## Results

### Preliminary analysis of IQ

The relationship between performance IQ and task performance of each group was analysed for all tasks. A significant positive relationship between PIQ and task performance was found among children with autism and 10-year-old children in the physics condition of multiple-choice task ( $r = 0.79$ ,  $p < 0.001$ ;  $r = 0.55$ ,  $p < 0.05$  respectively), and across all groups in the psychological condition of the multiple-choice task ( $r = 0.25$ ,  $p < 0.05$ ). In addition, a significant negative correlation was found between 7-year-olds on the psychological condition of the multiple-choice task ( $r = -0.66$ ,  $p < 0.05$ ). These findings made it necessary to control for PIQ when analysing performance in both conditions of this task.

### Task analysis

Analysis was carried out on the mean performance scores using one-way related ANOVAs. Analysis of the physics and psychological condition of the multiple-choice task was carried out using an ANCOVA (in order to include PIQ as a measure of covariance). Results are presented separately for each task.

### Picture sequencing

Overall there was a significant positive correlation between the psychological and physical conditions of this task ( $r = 0.414$ ,  $p < 0.001$ ).

A one-way ANOVA highlighted significant group differences in the mannade artefact condition ( $F(4, 89) = 6.02$ ,  $p < 0.001$ ). *Post hoc* Bonferroni *t*-tests indicated that there were significant differences between children with autism and both the 7-year-olds ( $t(37) = 1.12$ ,  $p < 0.05$ ) and 10-year-olds ( $t(36) = -1.74$ ,  $p < 0.001$ ). Inspection of the means showed that the children with autism were more likely to choose the physical picture to complete the picture sequence than the 7- and 10-year-olds (see Table 4 for means).

408

**Table 4** Performance mean (SD) of all five groups on both conditions of the picture sequencing task: scale 0 (all physics) to 4 (all psychology)

Group	Condition	
	Marmade	Natural
Preschoolers	2.06 (0.83)	2.59 (0.51)
7-year-olds	2.50 (1.12)	2.61 (0.92)
10-year-olds	3.12 (0.46)	2.65 (0.86)
Autism	1.38 (1.12)	1.43 (1.12)
CA match	2.33 (1.43)	2.62 (1.07)

A one-way ANOVA showed significant group differences in the natural artefact condition ( $F(4, 89) = 6.54, p < 0.001$ ). Post hoc Bonferroni *t*-tests revealed that significant differences lay between the children with autism and the other four groups: CA match ( $t(40) = -1.19, p < 0.001$ ); preschoolers ( $t(36) = -1.16, p < 0.01$ ); 7-year-olds ( $t(37) = -1.18, p < 0.01$ ); and 10-year-olds ( $t(36) = -1.22, p < 0.01$ ). The means illustrated that children with autism tended to opt more for the physical causal picture to complete the picture sequence than the other groups who preferred to complete the sequence with the psychological picture (see Table 4 for means).

### Categorization

Overall there was a significant positive correlation between the psychological and physical conditions of this task ( $r = 0.381, p < 0.001$ ). Further, a significant correlation was identified between the psychological categorization condition and the psychological condition of multiple-choice task ( $r = 0.28, p < 0.01$ ) and between the physics categorization condition and the physics condition of the multiple-choice task ( $r = 0.22, p < 0.01$ ). These results indicate that for each condition (physics and psychology) the categorization and multiple-choice tasks may be tapping knowledge from the relevant domain.

A one-way ANOVA indicated significant group differences in the physical categorization condition ( $F(4, 89) = 14.5, p < 0.001$ ). Post hoc Bonferroni *t*-tests indicated that there were significant differences between the 10-year-old children and the other four groups: children with autism ( $t(36) = 1.48, p = 0.05$ ); preschoolers ( $t(32) = 2.10, p = 0.001$ ); 7-year-olds ( $t(33) = 2.12, p < 0.01$ ); and CA match group ( $t(36) = 2.10, p < 0.01$ ). On inspection of the means it is clear that the 10-year-old children are more likely to categorize according to physical features than according to superficial features (see Table 5 for means). Although not significantly

409

### AUTISM 6(4)

**Table 5** Performance mean (SD) of all five groups on both conditions of the categorization task: scale 0 (all superficial) to 4 (all physics or psychology)

Group	Condition	
	Physical	Psychological
Preschoolers	0.65 (1.45)	1.70 (1.93)
7-year-olds	0.67 (1.28)	1.89 (1.99)
10-year-olds	2.76 (1.85)	3.06 (1.75)
Autism	1.28 (1.38)	1.76 (1.76)
CA match	0.67 (1.31)	1.81 (1.99)

different there was a clear trend in the data for children with autism to categorize more in terms of physical features than the CA match group.

Analysis indicated no significant differences between the five groups' performance in the psychological condition of this task. However, as indicated in Table 5, 10-year-olds were more likely to categorize according to psychological features than any other group.

### Multiple choice

Preliminary analysis revealed that the physical and the psychological subscales within the multiple-choice task were both highly reliable and could therefore be analysed separately (Cronbach's alpha 0.63 and 0.64 respectively).

Across all groups a significant negative correlation between performance on the two conditions was identified ( $r = -0.21, p < 0.05$ ). However, the correlations for each group, separately, were not significant.

The ANCOVA results showed a significant regression effect between the covariate PIQ and task performance on the physical condition ( $F(1, 88) = 11.3, p < 0.001$ ). When this was controlled a significant main effect of group was found ( $F(4, 88) = 17.24, p < 0.001$ ). Bonferroni *t*-tests on the adjusted means indicated that significant differences lay in task performance between the children with autism and the other four groups: CA match ( $t(40) = 4.3, p = 0.001$ ); preschoolers ( $t(36) = 3.9, p < 0.001$ ); 7-year-olds ( $t(37) = 5.0, p < 0.001$ ); and 10-year-olds ( $t(37) = 2.04, p < 0.01$ ). Differences were also found between the 10-year-old children and both the CA match group ( $t(40) = -2.26, p < 0.01$ ) and 7-year-olds ( $t(37) = 2.9, p < 0.001$ ). The adjusted means illustrated that the children with autism performed significantly better than the other four groups (see Table 6 for adjusted means).

As already mentioned PIQ was found to correlate with performance on the psychological condition of the multiple-choice task. However, when

410

**Table 6** Performance mean (SD) out of 12, when PIQ is controlled for, of all five groups on both conditions of the multiple-choice task

Group	Condition	
	Physical	Psychological
Preschoolers	4.04 (0.46)	9.83 (0.34)
7-year-olds	2.97 (0.48)	11.16 (0.35)
10-year-olds	5.93 (0.47)	11.46 (0.34)
Autism	7.97 (0.45)	7.65 (0.33)
CA match	3.67 (0.42)	10.25 (0.31)

analysed using a related ANCOVA with PIQ as a covariant, no significant effect was found. Using the adjusted means the ANCOVA revealed significant group differences in the psychological condition of this task ( $F(4, 88) = 18.27, p < 0.001$ ). *Post hoc* Bonferroni *t*-tests indicated that significant differences lay between children with autism and the other groups: CA match ( $t(40) = -2.59, p = 0.001$ ); preschoolers ( $t(36) = (2.17, p < 0.001)$ ); 7-year-old children ( $t(37) = -3.5, p < 0.001$ ); and 10-year-old children ( $t(36) = -3.81, p < 0.005$ ). Significant differences were also identified between preschool children and 10-year-old children ( $t(32) = -1.63, p < 0.05$ ). The means revealed that the children with autism performed significantly poorer on this task than the other groups.

## Discussion

Overall the present study found that children with autism, their CA matched peers, preschoolers, 7-year-old children and 10-year-old children demonstrated differentiated performance in most items. In general it appeared to be the case that, when given a choice of two responses, children with autism preferred the physical one. Further, as predicted, children with autism performed poorly in relation to tasks that tapped intuitive psychological knowledge whereas their performance on a task of intuitive physics was better than that demonstrated by both their CA matched peers and 10-year-old children. Performance on each task will now be discussed in turn.

The results of the picture sequencing task showed that in the physics condition children with autism were more likely to opt for the physical picture to complete the causal sequence than 7- and 10-year-old children who both preferred to opt for the psychological causal picture. Results did not indicate a difference in response patterns between the children with autism and the CA matched group or preschoolers. All three groups

## AUTISM 6(4)

preferred to choose the physical causal picture to complete the sequence. In the psychological condition, children with autism were more likely to choose the physical picture to complete the picture sequence. This was in contrast with the other groups of typically developing children who tended to opt for the picture depicting psychological causation. Taken together, these results suggest that children with autism may prefer to reason about causality in a purely physical way, employing this domain in relation to both physical and psychological phenomena. It should be noted, however, that the stimuli used may have influenced the findings. The stimuli depicting psychological causation included the common feature of a hand: in contrast, physical causation was represented by a range of agents. Despite this methodological issue, the results of this task show convincingly that, for children with autism, causal cognition in relation to psychology may be guided, at least in part, by intuitive physics.

The results of the categorization task showed that children with autism were less likely than 10-year-olds to categorize physically in the physics condition. It was expected that children with autism would show a preference for noticing salient physical laws but this was not identified. Although these results may indicate that the children with autism did not consistently attend to the physical laws there was a trend for children with autism to consider physical laws more often than the CA match. The lack of a significant preference to categorize according to fundamental physical features among children with autism may be due to task demands. The stimulus items included a large coloured area and this may have biased the children towards categorizing according to superficial colour features. Results suggested that only the oldest group of children (the 10-year-olds) identified the physical laws as salient and categorized accordingly.

The results indicated no differential pattern of response across groups in the psychological categorization condition where all groups preferred to categorize according to emotional features. This was not as expected since children with autism are well documented as having a difficulty with stimuli of a psychological nature. This led to the prediction that they would prefer to categorize according to superficial colour features. In addition, work has shown that preschool children would also sort according to superficial features (Gilbert, 1969) and this was not found. Again, these results may have been influenced by the task stimuli. The cards used in this condition were of simple drawn faces that depicted basic emotions and this may have lowered task demands compared with studies using photographs. Furthermore, the task mirrored some of the teaching that children with autism receive in school. For example, they are taught to recognize basic emotions such as happy and sad and some emotion sorting tasks were observed in the language units involved. Therefore, it



might have been better to depict more complex emotions via real photographs.

Performance on both conditions of the multiple-choice task was affected by performance IQ. When PIQ was controlled for in the analysis, it was found that children with autism performed more poorly than all other groups (even the preschoolers) on the intuitive psychology questions. This supports previous literature charting the difficulty that they have in reasoning about psychological phenomena such as desire and belief.

On the physical multiple-choice questions children with autism were shown to have performed significantly better than all other groups. Their performance, as well as being better than their CA matched peers, was also better than the 10-year-olds who were approximately 4 years older. This was not because the 10-year-old children performed poorly since they scored more highly than all other age groups of typically developing children. This result adds strength to the claim that children with autism have intact and superior knowledge in the domain of physics. The items in this task were adapted from published sources and worked well with the typically developing children. However, more normative data would be advantageous to further establish their reliability and validity.

It has recently been suggested that ability on intuitive psychology and physics tasks may represent a cognitive trade-off with both domains having the same underlying mechanism (Baron-Cohen et al., in press). In this study, performance between intuitive psychology and intuitive physics on the multiple-choice task across all groups revealed a significant inverse relationship. This may be evidence that both reasoning systems are indeed served by the same underlying mechanism. However, when group performance was analysed independently no correlation between the two conditions was identified. Moreover, positive (rather than negative) correlations were found between conditions in the picture sequencing and categorization tasks. This suggests that two independent structures (as proposed by the domain specificity literature) rather than a single cognitive mechanism may represent the two areas of reasoning. Clearly more investigation of this sort is needed in order to shed light on the underlying cognitive architecture of intuitive psychology and physics.

It has been said that cognition develops from its own foundations (Spelke et al., 1992). Thus individuals with autism who demonstrate a lack of psychological knowledge and an intact understanding of physical phenomena may have a specific underlying cognitive profile that reflects this. Within the literature many suggestions as to the precise cognitive structure of autistic spectrum disorders have been debated. Whatever the case may be, it is clear that children with autism do not effectively reason about psychological phenomena and may compensate by over-applying

their knowledge of intuitive physics to all types of phenomena. The findings of this study suggest that this cognitive strength may be a result of a precocious domain of intuitive physics (see also Baron-Cohen, 2000). Thus, these results indicate that among children with autistic spectrum disorders there is a coupling of impaired intuitive psychology and superior intuitive physics.

## Conclusion

This study supports the recurrent finding of impairment in understanding psychological phenomena in children with autism as well as adding to the claim that they have an intact and possibly superior understanding of intuitive physics. Importantly, the findings suggest that children with autism may prefer to view the world in a physical way, including phenomena that would be regarded by typically developing children as pertaining to the domain of psychology.

Taking these findings on board, future research should continue to investigate the nature of physical understanding among children with autism. A key focus should be to elucidate whether intuitive physics among children with autism is similar or superior to that of typically developing children. In addition, more in-depth work regarding the precise nature of understanding of physical phenomena among children with autism is needed to assert whether or not this knowledge is 'theoretical'. It could certainly be the case, for example, that they score highly on multiple-choice tasks asking about physical phenomena without having theoretical understanding (Gopnik et al., 2000). If research continues to reveal an advantage among children with autism in understanding physical phenomena, across a range of tasks, then the educational and therapeutic implications of this must be explored in order to capitalize on this potential cognitive strength.

## References

- AMERICAN PSYCHIATRIC ASSOCIATION (1994) *Diagnostic and Statistical Manual of Mental Disorders*, 4th edn (DSM-IV). Washington, DC: APA.
- BAILLARGEON, R., SPELKE, E.S. & WASSERMANN, S. (1985) 'Object Permanence in 5-Month-Old Infants', *Cognition* 20: 191-208.
- BARON-COHEN, S. (1989) 'Are Autistic Children "Behaviourists"? An Examination of Their Mental-Physical and Appearance-Reality Distinctions', *Journal of Autism and Developmental Disorders* 19: 579-600.
- BARON-COHEN, S. (1997) 'Are Children with Autism Superior at Folk Physics?', in H. WELLMAN & K. INAGAKI (eds) *The Emergence of Core Domains of Thought: Children's Reasoning about Physical, Psychological and Biological Phenomena*. San Francisco: Jossey-Bass.
- BARON-COHEN, S. (2000) 'Autism: Deficits in Folk Psychology Exist Alongside Superiority in Folk Physics', in S. BARON-COHEN, H. TAGER-FLUSBERG & D.J.



- COHEN (eds) *Understanding Other Minds: Perspectives from Developmental Cognitive Neuroscience*, pp. 73-83. Oxford: Oxford University Press.
- BARON-COHEN, S. & BOLTON, P. (1993) *Autism: The Facts*. Oxford: Oxford University Press.
- BARON-COHEN, S. & HAMMER, J. (1997) 'Parents of Children with Asperger Syndrome: What Is the Cognitive Phenotype?', *Journal of Cognitive Neuroscience* 9: 548-54.
- BARON-COHEN, S. & WHEELWRIGHT, S. (1999) 'Obsessions in Children with Autism or Asperger Syndrome: A Content Analysis in Terms of Core Domains of Cognition', *British Journal of Psychiatry* 175: 484-90.
- BARON-COHEN, S., LESLIE, A.M. & FRITH, U. (1985) 'Does the Autistic Child Have a "Theory of Mind"?', *Cognition* 21: 37-46.
- BARON-COHEN, S., LESLIE, A.M., & FRITH, U. (1986) 'Mechanical, Behavioural and Intentional Understanding of Picture Stories in Autistic Children', *British Journal of Developmental Psychology* 4: 113-25.
- BARON-COHEN, S., JOLIFFE, T., MORTIMORE, C. & ROBERTSON, M. (1997) 'Another Advanced Test of Theory of Mind: Evidence from Very High Functioning Adults with Autism or Asperger Syndrome', *Journal of Child Psychology and Psychiatry* 38: 813-22.
- BARON-COHEN, S., WHEELWRIGHT, S., SPONG, A., SCARILL, V. & LAWSON, J. (in press) 'Are Intuitive Physics and Intuitive Psychology Independent? A Test with Children with Asperger Syndrome', *Journal of Developmental and Learning Disorders*.
- BETTELHEIM, B. (1968) *The Empty Fortress*. Chicago: Free Press.
- BINNIE, L.M. & WILLIAMS, J.M. (in press) 'Intuitive Psychological, Physical and Biological Knowledge in Typically Developing Pre-Schoolers, Children with Autism and Children with Down Syndrome', *British Journal of Developmental Psychology*.
- BOWLER, D.M. & THOMMEN, E. (2000) 'Attribution of Mechanical and Social Causality to Animated Displays by Children with Autism', *Autism* 4 (2): 147-71.
- DAS GUPTA, P. & BRYANT, P.E. (1989) 'Young Children's Causal Inferences', *Child Development* 60: 1138-46.
- DAWSON, G., MELTZOFF, A.N., OSTERLING, J. & RINALDI, J. (1998) 'Children with Autism Fail to Orient to Naturally Occurring Social Stimuli', *Journal of Autism and Developmental Disorders* 28: 479-85.
- DISESSA, A.A. (1998) 'What do "Just Plain Folk" Know about Physics?', in D.R. OLSON & N. TORRANCE (eds) *The Handbook of Education and Human Development: New Models of Learning, Teaching and Schooling*, pp. 709-30. Oxford: Blackwell.
- DUNN, L.M., DUNN, L.M., WHETTON, C. & BURLEY, J. (1997) *The British Picture Vocabulary Scale, Second Edition*. Windsor: NFER-Nelson.
- GEIMAN, R., BULLOCK, M. & MECK, E. (1980) 'Preschoolers' Understanding of Simple Object Transformations', *Child Development* 52: 691-9.
- GILBERT, D. (1969) 'The Young Child's Awareness of Affect', *Child Development* 39: 619-36.
- GOPNIK, A., CAPPS, L. & MELTZOFF, A.N. (2000) 'Early Theories of Mind: What the Theory Can Tell Us about Autism', in S. BARON-COHEN, H. TAGER-FLUSBERG & D.J. COHEN (eds) *Understanding Other Minds: Perspectives from Developmental Cognitive Neuroscience*, pp. 50-73. Oxford: Oxford University Press.
- GUNNAR, M.R. & MARATOS, M. (1992) *Modularity and Constraints in Language and Cognition: The Minnesota Symposia on Child Psychology*. Vol. 25. Hillsdale, NJ: Erlbaum.
- HARRIS, P., JOHNSON, C.N., HUTTON, D., ANDREWS, G. & COOKE, T. (1989) 'Young Children's Theory of Mind and Emotion', *Cognition and Emotion* 3: 379-400.
- HEYMAN, G.D. & DWEEK, C.S. (1998) 'Children's Thinking about Traits: Implications for Judgement of Self and Others', *Child Development* 69: 391-403.
- HOWE, J.C. (1998) *Conceptual Structure in Childhood and Adolescence: The Case of Everyday Physics*. London: Routledge.
- HOWLIN, P., BARON-COHEN, S. & HADWIN, J. (1999) *Teaching Children with Autism to Mind-Read*. Chichester: Wiley.
- JOHNSON, C.N. & WELLMAN, H.M. (1982) 'Children's Developing Conceptions of the Mind and Brain', *Child Development* 53: 222-34.
- KAISER, M.K., MCCLOSKEY, M. & PROFFITT, D.R. (1985) 'The Development of Beliefs about Falling Objects', *Perception & Psychophysics* 38 (6): 533-9.
- KAISER, M.K., MCCLOSKEY, M. & PROFFITT, D.R. (1986) 'Development of Intuitive Theories of Motion: Curvilinear Motion in the Absence of External Forces', *Developmental Psychology* 22: 67-71.
- KANNER, L. (1943) 'Autistic Disturbances of Affective Contact', *Nervous Child* 2: 217-50.
- KIM, I. & SPELKE, E.S. (1999) 'Perception and Understanding of Effects of Gravity and Inertia on Object Motion', *Developmental Science* 2 (3): 339-62.
- LEE, K. & HOMER, B. (1999) 'Children as Folk Psychologists: The Developing Understanding of Mind', in A. SLATER & D. MUIR (eds) *The Blackwell Reader in Developmental Psychology*, pp. 228-52. Oxford: Blackwell.
- LEEKAM, S.R. & PERNER, J. (1991) 'Does the Autistic Child Have a Representational Deficit?', *Cognition* 40: 203-18.
- LESLIE, A.M. (1987) 'Preference and Representations: The Origins of "Theory of Mind"', *Psychological Review* 94: 412-26.
- LESLIE, A.M. (1994) 'ToMM, ToBY, and Agency: Core Architecture and Domain Specificity', in L.A. HIRSCHFIELD & S.A. GEIMAN (eds) *Mapping the Mind: Domain Specificity in Cognition and Culture*, pp. 169-200. Cambridge: Cambridge University Press.
- MELTZOFF, A.N. & MOORE, M.K. (1977) 'Imitation of Facial and Manual Gestures by Human Neonates', *Science* 198 (4312): 75-8.
- METZ, K. (1985) 'The Development of Children's Problem Solving in a Gears Task: A Problem Space Perspective', *Cognitive Science* 9: 431-71.
- MUNDY, P. & CROWSON, M. (1997) 'Joint Attention and Early Social Communication', *Journal of Autism and Developmental Disorders* 27: 653-76.
- MURPHY, G.L. & MEDIN, D.L. (1985) 'The Role of Theories in Conceptual Coherence', *Psychological Review* 92: 289-316.
- PETERSEN, C.C. & SIEGAL, M. (1998) 'Changing Focus on the Representational Mind: Deaf, Autistic and Normal Children's Concepts of False Photos, False Drawings and False Beliefs', *British Journal of Developmental Psychology* 16: 301-20.
- PIAGET, J. (1930) *The Child's Conception of Physical Causality*. New York: Harcourt Brace Jovanovich.
- PRATT, C. & BRYANT, P.E. (1990) 'Young Children Understand that Looking Leads to Knowing (As Long As They Are Looking into a Single Barrel)', *Child Development* 61 (4): 973-82.
- SAVITSKY, J.C. & IZARD, C.E. (1970) 'Developmental Changes in the Use of Emotion Cues in a Concept-Formation Task', *Developmental Psychology* 3: 350-7.
- SIEGLER, R. (1976) 'Three Aspects of Cognitive Development', *Cognitive Psychology* 8: 481-520.
- SMITH, C., CAREY, S. & WISER, M. (1985) 'On Differentiation: A Case Study of the Development of the Concepts of Size, Weight and Density', *Cognition* 21: 177-237.

- SPEIKE, E.S., BREINLINGER, K., MACOMBER, J. & JACKSON, K. (1992) 'Origins of Knowledge', *Psychological Review* 99: 605-32.
- SPEIKE, E.S., PHILLIPS, A. & WOODWARD, A.L. (1995) 'Infants' Knowledge of Object Motion and Human Action', in D. SPERBER, D. PREMACK & A.J. PREMACK (eds) *Causal Cognition: A Multidisciplinary Debate*, pp. 44-78. Oxford: Clarendon.
- SPERBER, D., PREMACK, D. & PREMACK, A. (1995) *Causal Cognition: A Multidisciplinary Debate*. Oxford: Oxford University Press.
- WECHSLER, D. (1990) *Wechsler Pre-school and Primary Scale of Intelligence (WPPSI)*. London: Psychological Corporation.
- WECHSLER, D. (1992) *Wechsler Intelligence Scale for Children (WISC)*. London: Psychological Corporation.
- WEEKS, S.J. & HOBSON, R.P. (1987) 'The Salience of Facial Expression for Autistic Children', *Journal of Child Psychology and Psychiatry* 28 (1): 137-52.
- WILLMAN, H. (1990) *The Child's Theory of Mind*. Cambridge, MA: MIT Press.
- WILLMAN, H.M. & GELMAN, S.A. (1992) 'Cognitive Development: Foundational Theories and Core Domains', *Annual Review of Psychology* 43: 337-75.
- WILLMAN, H.M. & INAGAKI, K. (1997) *The Emergence of Core Domains of Thought: Children's Reasoning about Physical, Psychological and Biological Phenomena*. San Francisco: Jossey-Bass.
- WILLMAN, H.M., HICKING, A.K. & SHULTZ, C.A. (2000) 'Young Children's Psychological, Physical and Biological Explanations', in K. LEE (ed.) *Childhood Cognitive Development: The Essential Readings*. Oxford: Blackwell.
- WILLIAMS, E., COSTALL, A. & REDDY, V. (1999) 'Children with Autism Experience Problems with Both Objects and People', *Journal of Autism and Developmental Disorders*, 29 (5): 367-78.
- WIMMER, H. & PERNER, J. (1983) 'Beliefs about Beliefs: Representation and Constraining Function of Wrong Beliefs in Young Children's Understanding of Deception', *Cognition* 13: 103-28.
- WING, L. (1969) 'The Handicaps of Autistic Children - A Comparative Study', *Journal of Child Psychology and Psychiatry* 10: 1-23.
- WORLD HEALTH ORGANIZATION (1992) *The ICD-10 Classification of Mental and Behavioural Disorders: Clinical Description and Diagnostic Guidelines*. Geneva: WHO.
- ZAITCHIK, D. (1990) 'When Representations Conflict with Reality: The Pre-Schooler's Problem with False Belief and False Photographs', *Cognition* 35: 41-68.

## REFERENCES

- Adrien, J. L., Lenior, P., Martineau, J., & Perrot, A. (1993). Blind Ratings of Early Symptoms Based upon Family Home Movies. *Journal of the American Academy of Child and Adolescent Psychiatry*, 32, 617-626.
- American Psychiatric Association. (1994). *Diagnostic and Statistical Manual of Mental Disorders* ( Vol. 4th). Washington DC: American Psychiatric Association.
- Amsel, E., Goodman, G., Savoie, D., & Clark, M. (1996). The Development of Reasoning about Causal and Noncausal Influences on Levers. *Child Development*, 67, 1624 - 1646.
- Anderson, K., & Wilkening, F. (1991). Adaptive Thinking in Intuitive Physics. In K. Anderson (Ed.), *Contributions to Information Integration Theory* (Vol. 3, pp. 45-80). Hillsdale, N. J.: Lawrence Erlbaum Associates Inc.
- Anderson, N. H. (1983). Intuitive Physics: Understanding and Learning of Physical Relations. In J. S. Tighe, B. E. (Ed.), *Perception, Cognition and Development* (pp. 231 - 265). Hillsdale: New Jersey: Lawrence Erlbaum Associates Inc.
- Arbelle, S., Sigman, M. D., & Kasari, C. (1994). Compliance with Parental Prohibition in Autistic Children. *Journal of Autism and Developmental Disorders*, 24, 693-702.
- Astington, J. P., & Gopnik, A. (1991). Theoretical Explanations of Children's Understanding of the Mind. *British Journal of Developmental Psychology*(9), 7-31.
- Atran, S. (1994). Core Domains versus Scientific Theories: Evidence from Systematics and Itzaj-Maya Folk Biology. In L. A. Hirschfeld & S. A. Gelman (Eds.), *Mapping The Mind: Domain Specificity in Cognition and Culture* (pp. 316-340). Cambridge: Cambridge University Press.
- Atran, S. (1999). Itzaj Maya Folkbiology Taxonomy: Cognitive Universals and Cultural particulars. In D. L. Medin & S. Atran (Eds.), *Folkbiology* (pp. 119-204). Cambridge MA: MIT Press.
- Attwood, A. J., Frith, U., & Hermelin, B. (1988). Understanding and Use of Interpersonal Gestures by Autistic and Down's Syndrome Children. *Journal of Autism and Developmental Disorders*, 18, 241-257.
- Bailey, A., Palferman, S., Heavey, L., & Le Couteur, A. (1998). Autism: The Phenotype in Relatives. *Journal of Autism and Developmental Disorders*, 28, 369-392.

- Bailey, A., Phillips, W., & Rutter, M. (1996). Autism: Towards an Integration of Clinical, Genetic, Neuropsychological and Neurobiological Perspectives. *Journal of Child Psychology and Psychiatry*, 37, 89 - 126.
- Bailey, T., Le Couteur, A., Gottesman, I., Bolton, P., Simonoff, E., Yuzda, E., & Rutter, M. (1995). Autism as a Strongly Genetic Disorder: Evidence from a British Twin Study. *Psychological Medicine*, 25, 63-77.
- Baillargeon, R. (1986). Representing the Existence and Location of Hidden Objects: Object Permanence in 6 and 8-Month Old Infants. *Cognition*, 23, 21-41.
- Baillargeon, R. (1987a). Object Permanence in 3.5 and 4.5-Month Old Infants. *British Journal of Developmental Psychology*, 23, 655-664.
- Baillargeon, R. (1987b). Young Infants Reasoning about the Physical and Spatial Properties of a Hidden Object. *Cognitive Development*, 2, 179-200.
- Baillargeon, R. (2000). How do Infants Learn about the Physical World? In D. Muir & A. Slater (Eds.), *Infant Development: The Essential Readings* (pp. 195-212). Oxford: Blackwell.
- Baillargeon, R., & De Vos, J. (1991). Object Permanence in Young Infants: Further Evidence. *Child Development*, 62, 1227-1246.
- Baillargeon, R., & Gelman, R. (1980). *Young Children's Understanding of Simple Causal Sequences: Predictions and Explanations*. Paper presented at the American Psychological Society, Montreal.
- Baillargeon, R., Kotovsky, L., & Needham, A. (1995). The Acquisition of Physical Knowledge in Infancy. In D. Sperber & D. Premack & A. J. Premack (Eds.), *Causal Cognition: A Multidisciplinary Debate* (pp. 79-116). Oxford: Oxford University Press.
- Baillargeon, R., Spelke, E. S., & Wassermann, S. (1985). Object Permanence in 5-month-old Infants. *Cognition*, 20, 191-208.
- Baldwin, D. A., & Moses, L. J. (1994). Early Understanding of Referential Intent and Attentional Focus: Evidence from Language and Emotion. In C. Lewis & P. Mitchell (Eds.), *Children's Early Understanding of Mind: Origins and Development* (pp. 133-156). Hillsdale, N. J.: Erlbaum.
- Baron-Cohen, S. (1989a). Are Autistic Children really 'Behaviourists'? An Examination of their Mental-Physical and Appearance Reality Distinctions. *Journal of Autism and Developmental Disorders*, 19, 579-600.
- Baron-Cohen, S. (1989b). Perceptual Role Taking and Proto-declarative Pointing in Autism. *British Journal of Developmental Psychology*, 7, 113-127.



- Baron-Cohen, S. (1989c). The Autistic Child's Theory of Mind: A Case of Specific Developmental Delay. *Journal of Child Psychology and Psychiatry*, 30(2), 285-297.
- Baron-Cohen, S. (1991). Theory of Mind Deficit in Autism: How Specific is it? *British Journal of Developmental Psychology*, 9, 301-314.
- Baron-Cohen, S. (1992). Out of Sight or Out of Mind: Another Look at Deception in Autism. *Journal of Child Psychology and Psychiatry*, 33, 1141-1455.
- Baron-Cohen, S. (1995). *Mindblindness: An Essay on Autism and Theory of Mind*. Cambridge M.A.: MIT Press.
- Baron-Cohen, S. (1997). Are Children with Autism Superior at Folk Physics? In H. Wellman & K. Inagaki (Eds.), *The Emergence of Core Domains of Thought: Children's Reasoning about Physical, Psychological and Biological Phenomena. New Directions for Child Development* (Vol. 75, pp. 45-55). San Francisco: CA: Jossey Bass.
- Baron-Cohen, S. (2000a). Theory of Mind and Autism: A Fifteen Year Review. In S. Baron-Cohen & H. Tager-Flusberg & D. Cohen (Eds.), *Understanding Others Minds: Perspectives from Developmental Cognitive Neuroscience* (pp. 3-20). Oxford: Oxford University Press.
- Baron-Cohen, S. (2000b). Autism: Deficits in Folk Psychology Exist Alongside Superiority in Folk Physics. In S. Baron-Cohen & H. Tager-Flusberg & D. J. Cohen (Eds.), *Understanding Others Minds: Perspectives from Developmental Cognitive Neuroscience* (pp. 73-83). Oxford: Oxford University Press.
- Baron-Cohen, S., Allen, J., & Gillberg, C. (1992). Can Autism be Detected at 18 months? The needle in the haystack and the CHAT. *British Journal of Psychiatry*, 161, 839-843.
- Baron-Cohen, S., Bolton, P., Wheelwright, S., Short, L., Mead, G., Smith, A., & Scahill, V. (1998). Autism Occurs More in Families of Physicists, Engineers, and Mathematicians. *Autism: An International Journal of Research and Practice*, 2, 296 - 301.
- Baron-Cohen, S., Campbell, R., Karmiloff-Smith, A., Grant, J., & Walker, J. (1995). Are Children with Autism Blind to the Mentalistic Significance of the Eyes? *British Journal of Developmental Psychology*, 13, 379-398.
- Baron-Cohen, S., & Goodhart, F. (1994). The 'Seeing Leads to Knowing' Deficit in Autism: The Pratt and Bryant Probe. *British Journal of Developmental Psychology*(12), 397-402.
- Baron-Cohen, S., & Hammer, J. (1997). Parents of Children with Asperger's Syndrome; What is the Cognitive Phenotype? *Journal of Cognitive Neuroscience*, 9, 548-554.

- Baron-Cohen, S., Jolliffe, T., Mortimore, C., & Robertson, M. (1997). Another Advanced Test of Theory of Mind: Evidence from Very High Functioning Adults with Autism or Asperger Syndrome. *Journal of Child Psychology and Psychiatry*, 38, 813-822.
- Baron-Cohen, S., Leslie, A. M., & Frith, U. (1985). Does the Autistic Child have a 'Theory of Mind'. *Cognition*, 21, 37-46.
- Baron-Cohen, S., Leslie, A. M., & Frith, U. (1986). Mechanical, Behavioural and Intentional Understanding of Picture Stories in Autistic Children. *British Journal of Developmental Psychology*, 4, 113-125.
- Baron-Cohen, S., Spitz, A., & Cross, P. (1993). Can Children with Autism Recognise Surprise? *Cognition and Emotion*(7), 507-516.
- Baron-Cohen, S., & Swettenham, J. G. (1997). Theory of Mind in Autism: It's Relationship to Executive Functioning and Central Coherence. In D. Cohen & F. Volkmar (Eds.), *Handbook of Autism*. London: Wiley.
- Baron-Cohen, S., Tager-Flusberg, H., & Cohen, D. J. (2000). *Understanding Others Minds: Perspectives from Developmental Cognitive Neuroscience*. Oxford: Oxford University Press.
- Baron-Cohen, S., & Wheelwright, S. (1999). 'Obsessions' in Children with Autism or Asperger's Syndrome: Content Analysis in Terms of Core Domains of Cognition. *British Journal of Psychiatry*, 175, 484-490.
- Baron-Cohen, S., Wheelwright, S., Spong, A., Scahill, V., & Lawson, J. (2001). Studies of Theory of Mind: Are Intuitive Physics and Intuitive Psychology Independent? *Journal of Developmental and Learning Disorders*, 5(1), 51-82.
- Baron-Cohen, S., Wheelwright, S., Stott, C., Bolton, P., & Goodyer, I. (1997). Is there a Link Between Engineering and Autism? *Autism: An International Journal of Research and Practice*, 1, 153-163.
- Bartsch, K., & Wellman, H. (1989). Young Children's Attribution of Action to Beliefs and Desires. *Child Development*, 60, 946-964.
- Bartsch, K., & Wellman, H. M. (1995). *Children Talk about the Mind*. New York: Oxford University Press.
- Bertenthal, B. I., Proffitt, H. D. R., & Kramer, S. J. (1987). Perception of Biomechanical Motions by Infants: Implementation of Various Processing Constraints. *Journal of Experimental Psychology: Human Perception and Performance*, 13, 577-585.

- Berthenthal, B. I., Proffit, H. D. R., Spetner, N. B., & Thomas, M. A. (1985). The Development of Infant Sensitivity to Biomechanical Motions. *Child Development*, 56, 531-543.
- Biddulph, F. (1983). *Students View of Floating and Sinking, Learning in Science Projects, Working Paper No. 116*. Waikato: University of Waikato.
- Black, M., Freeman, B. J., & Montgomery, J. (1975). Systematic Observations of Play Behaviour in Autistic Children. *Journal of Autism and Developmental Disorders*, 15, 363-371.
- Blomquist, H. K., Bohmna, M., Edvinsson, S. O., Gillberg, C., Gustavon, K. M., Holmgren, C., & Wahlstrom, J. (1985). Frequency of Fragile-X-syndrome in Infantile Autism; A Swedish Multicentre Study. *Clinical Genetics*, 27, 113-117.
- Bloom, P., & German, T. (2000). Two Reasons to Abandon the False Belief Task as a Test of Theory of Mind. *Cognition*, 77, B25-B31.
- Bolton, P., MacDonald, H., Pickles, A., Rios, P., Goodes, S., Crowson, M., Bailey, A., & Rutter, M. (1994). A Case-control Family History Study of Autism. *Journal of Child Psychology and Psychiatry*, 35, 877-900.
- Bowler, D. M., & Thommen, E. (2000). Attribution of Mechanical and Social Causality to Animated Displays by Children with Autism. *Autism: An International Journal of Research and Practice*, 4(2), 147-171.
- Brazelton, T. B., Koslowski, B., & Main, M. (1974). The Origins of Reciprocity: The Early Mother-Infant Interaction. In M. Lewis & L. A. Rosenblum (Eds.), *The Effect of Infant on it's Caregiver* (pp. 49-76). New York: Wiley.
- Bretherton, I., & Beeghly, M. (1982). Talking about Internal States: The Acquisition of an Explicit Theory of Mind. *Developmental Psychology*, 18, 906-921.
- Brown, A. L., Metz, K. E., & Campione, J. C. (1996). Social Interaction and Individual Understanding in a Community of Learners: The Influence of Piaget and Vygotsky. In A. Tryphon & J. Voneche (Eds.), *Piaget-Vygotsky: The Social Genesis of Thought* (pp. 145-170). Hove, UK: Psychology Press.
- Bullock, M., & Gelman, R. (1979). Pre-school Children's Assumptions about Cause and Effect: Temporal Ordering. *Child Development*, 50, 89-96.
- Bullock, M., Gelman, R., & Baillargeon, R. (1982). The Development of Causal Reasoning. In W. J. Freidman (Ed.), *The Developmental Psychology of Time* (pp. 209-254). New York: Academic.

- Burack, J. A., Charman, T., Yirmiya, N., & Zelazo, P. R. (Eds.). (2001). *The Development of Autism: Perspectives from Theory and Research*. Mahwah: New Jersey: Lawrence Erlbaum Associates.
- Butterworth, G. E. (1991). The Ontogeny and Phylogeny of Joint Visual Attention. In A. Whiten (Ed.), *Natural Theories of Mind* (pp. 223-232). Oxford: Basil Blackwell.
- Carey, S. (1985). *Conceptual Change in Childhood*. Cambridge, MA.: MIT Press.
- Carey, S. (1990). Cognitive Domains as Modes of Thought. In D. R. Olsen & N. Torrance (Eds.), *Modes of Thought* (pp. 187-215). Cambridge: Cambridge University Press.
- Carey, S. (1991). Knowledge Acquisition: Enrichment or Conceptual Change? In S. Carey & S. A. Gelman (Eds.), *The Epigenesis of Mind* (pp. 257-292). New York: Lawrence Erlbaum Associates.
- Carey, S. (1995). On the Origins of Causal Understanding. In D. Sperber & D. Premack & A. J. Premack (Eds.), *Causal Cognition: A Multidisciplinary Debate* (pp. 268-302). Oxford: Clarendon Press.
- Carey, S. (1996). Cognitive Domains as Modes of Thought. In D. Olson & N. Torrance (Eds.), *Modes of Explanation in Culture and Cognition* (pp. 187-215). New York: Cambridge University Press.
- Carey, S. (2001). *Conceptual Change in Three Core Domains of Thought*. Paper presented at the Society for Research in Child Development, Minneapolis.
- Carey, S., & Gelman, R. (1991). *The Epigenesis of Mind: Essays on Biology and Cognition*. Hillsdale, N. J.: Erlbaum.
- Carey, S., & Markman, E. M. (1999). Cognitive Development. In B. Martin-Bly & D. E. Rumelhart (Eds.), *Cognitive Science: Handbook of Perception and Cognition* (pp. 201-254). London: Academic Press.
- Carey, S., & Spelke, E. S. (1994). Domain-specificity and Conceptual Change. In L. A. Hirschfeld & S. A. Gelman (Eds.), *Mapping The Mind: Domain Specificity in Cognition and Culture* (pp. 169-200). Cambridge: Cambridge University Press.
- Carlson, S. M., Moses, L. J., & Hix, H. R. (1998). The Role of Inhibitory Processes in Young Children's Difficulties with Deception and False Belief. *Child Development*, 69, 672-691.
- Carpendale, J., & Chandler, M. J. (1996). On the Distinction Between False Belief Understanding and Subscribing to an Interpretive Theory of Mind. *Child Development*, 67, 1686-1706.



- Carpenter, M., Nagell, K., & Tomasello, M. (1998). Social Cognition, Joint Attention, and Communicative Competence from 9 to 15 Months of Age. *Monographs for the Society for Research in Child Development*, 63(4), Serial No: 255.
- Chandler, M., Fritz, A. S., & Hala, S. (1989). Small Scale Deceit: Deception as a Marker of 2, 3 and 4-year-olds Early Theories of Mind. *Child Development*, 60, 1263-1277.
- Chandler, M. J., & Lalonde, C. (1996). Shifting to an Interpretative Theory of Mind: 5- to 7-year-olds' Changing Conceptions of Mental Life. In A. Sameroff & M. Haith (Eds.), *Reason and Responsibility: Passage Through Childhood* (pp. 111-139). Chicago, Illinois: University of Chicago Press.
- Chapman, M. (1988). *Constructive Evolution: Origins and Development of Piaget's Thought*. Cambridge: Cambridge University Press.
- Charman, T., & Campbell, A. (1997). Reliability of Theory of Mind Task Performance by Individuals with a Learning Disability. *Journal of Child Psychology and Psychiatry*, 38, 725-730.
- Chomsky, N. (1980). *Rules and Representations*. New York: Columbia University Press.
- Chomsky, N. (1988). *Language and Problems of Knowledge*. Cambridge MA: MIT Press.
- Cicchetti, D. (1984). The Emergence of Developmental Psychopathology. *Child Development*, 55, 1 - 7.
- Clark, A. (1987). From Folk Psychology to Naive Psychology. *Cognitive Science*, 11, 139-154.
- Cosmides, L. (1997). *Evolutionary Psychology*. Paper presented at the Annual Conference of the British Psychological Society, Edinburgh.
- Cosmides, L., & Tooby, J. (1994). *Origins of Domain Specificity: The Evolution of Functional Organisation*. Cambridge: Cambridge University Press.
- Das Gupta, P., & Bryant, P. E. (1989). Young Children's Causal Inferences. *Child Development*, 60, 1138-1146.
- Dawson, G., Meltzoff, A. N., Osterling, J., & Rinaldi, J. (1998). Children with Autism Fail to Orient to Naturally Occurring Social Stimuli. *Journal of Autism and Developmental Disorders*, 28, 479-485.
- Dennett, D. (1971). Intentional systems. *Journal of Philosophy*, 68, 87-106.
- Dennett, D. (1978). *Brainstorms*. Montgomery: Bradford Books.

- Diamond, A. A. (1991). Neuropsychological Insights into the Meaning of Object Concept Development. In S. Carey & S. A. Gelman (Eds.), *The Epigenesis of Mind* (pp. 67-110). New Jersey: Lawrence Erlbaum Associates.
- Disessa, A. A. (1998). What do 'Just Plain Folk' Know about Physics? In D. R. Olsen & N. Torrance (Eds.), *The Handbook of Education and Human Development: New Models of Learning, Teaching and Schooling* (pp. 709-730). Oxford: Blackwell.
- Donaldson, M. (1979). *Children's Minds*. London: Fontana.
- Donaldson, M. L., & Elliot, A. (1990). Children's Explanations. In R. Grieve & M. Hughes (Eds.), *Understanding Children* (pp. 26-50). Oxford: Blackwell.
- Dunn, L. M., Dunn, L. M., Whetton, C., & Burley, J. (1997). *The British Picture Vocabulary Scale (BPVS)* (2 ed.). Windsor: NFER-Nelson.
- Estes, D., Wellman, H., & Woolley, J. D. (1990). Children's Understanding of Mental Phenomena. In H. Reese (Ed.), *Advances in Child Development and Behaviour* (pp. 41-87). New York: Academic Press.
- Fagan, J. F. (1972). Infants' Recognition Memory for Faces. *Journal of Experimental Child Psychology*, 14, 453-476.
- Fagan, J. F. (1976). Infants Recognition of Invariant Features of Faces. *Child Development*, 47, 627-633.
- Flavell, J. H. (1977a). The Development of Knowledge about Visual Perception. *Nebraska Symposium on Motivation: Social Cognitive Development*, 25, 43-76.
- Flavell, J. H. (1977b). *Cognitive Development*. Englewood Cliffs, NJ: Prentice-Hall.
- Flavell, J. H. (1978). The Development of Knowledge about Perception. In C. B. Keasey (Ed.), *Nebraska Symposium on Motivation*. Lincoln: University of Nebraska Press.
- Flavell, J. H. (1984). Discussion. In R. J. Sternberg (Ed.), *Mechanisms of Cognitive Change* (pp. 187-209). New York: Freeman.
- Flavell, J. H. (2000). Cognitive Development: Past, Present and Future. In K. Lee (Ed.), *Childhood Cognitive Development: The Essential Readings* (pp. 7-31). Oxford: Blackwell.
- Flavell, J. H., Flavell, E. R., & Green, F. L. (1983). Development of the Appearance-Reality Distinction. *Cognitive Psychology*, 15, 95-120.
- Flavell, J. H., Green, F. L., & Flavell, E. R. (1986). Development of Knowledge about the Appearance Reality Distinction. *Monographs for the Society for Research in Child Development*, 51(212).

- Flavell, J. H., Green, F. L., & Flavell, E. R. (1993). Children's Understanding of the Stream of Consciousness. *Child Development*, 64, 387-398.
- Flavell, J. H., Green, F. L., & Flavell, E. R. (1995). Young Children's Knowledge of Thinking. *Monographs of the Society for Research in Child Development*, 243.
- Flavell, J. H., Green, F. L., & Flavell, E. R. (1998). The Mind has a Mind of its Own: Developing Knowledge about Mental Uncontrollability. *Cognitive Development*, 13, 127-128.
- Fodor, J. (1975). *The Language of Thought*. New York: Crowell.
- Fodor, J. (1983). *The Modularity of Mind*. Cambridge MA: MIT Press.
- Fodor, J. (1987). *Psychosemantics: The Problem of Meaning in the Philosophy of Mind*. Cambridge MA: MIT Press.
- Fodor, J. (1992). The Theory of Children's Theory of Mind. *Cognition*, 44, 283-296.
- Folstein, S., & Rutter, M. (1977a). Infantile Autism: A Genetic Study of 21 Twin Pairs. *Journal of Child Psychology and Psychiatry*, 18, 297-321.
- Folstein, S., & Rutter, M. (1977b). Genetic Influences and Infantile Autism. *Nature*, 265, 726-728.
- Forguson, L., & Gopnik, A. (1988). The Ontogeny of Common Sense. In J. P. Astington & P. Olson & D. Harris (Eds.), *Developing Theories of Mind* (pp. 226-243). Cambridge: Cambridge University Press.
- Freeman, N. H., Lewis, C., & Docherty, M. J. (1991). Preschoolers Grasp of a Desire for Knowledge in False Belief Prediction: Practical Intelligence and Verbal Report. *British Journal of Developmental Psychology*, 9, 7-31.
- Freeman, S. F. N., & Hodapp, R. M. (2000). Educating Children with Down syndrome: Linking Behavioural Characteristics to Promising Intervention Strategies. *Down Syndrome Quarterly*, 5, 1-9.
- Frith, C., & Frith, U. (2000). The Physiological Basis of Theory of Mind: Functional Neuroimaging Studies. In S. Baron-Cohen & H. Tager-Flusberg & D. Cohen (Eds.), *Understanding Other Minds: Perspectives from Developmental Cognitive Neuroscience* (pp. 334 - 356). Oxford: Oxford University Press.
- Frith, U. (1989). *Explaining the Enigma*. Oxford: Blackwell.
- Frith, U. (1991). *Autism and Asperger's Syndrome*. Cambridge: Cambridge University Press.

- Frith, U. (1999). Cognitive Development and Cognitive Deficit. In A. Slater & D. Muir (Eds.), *The Blackwell Reader in Development Psychology* (pp. 509-522). Malden MA, USA: Blackwell.
- Frith, U., & Happe, F. (1994). Autism Beyond 'Theory of Mind'. *Cognition*, 50, 115-132.
- Frith, U., Happe, F., & Siddons, F. (1994). Autism and Theory of Mind in Everyday Life. *Social Development*, 3, 108-124.
- Gelman, R. (1990). First Principles Organise Attention to and Learning about Relevant Data: Number and the Animate-Inanimate Distinction as Examples. *Cognitive Science*, 14, 79-106.
- Gelman, R., Bullock, M., & Meck, E. (1980). Preschooler's Understanding of Simple Object Transformations. *Child Development*, 52, 691-699.
- Gelman, R., Spelke, E. S., & Meck, E. (1983). What Pre-schoolers Know About Animate and Inanimate Objects. In D. Rodgers & J. A. Sloboda (Eds.), *The Acquisition of Symbolic Skills* (pp. 297-234). New York: Plenum.
- Gelman, S. A., & Wellman, H. (1991). Insides and Essences: Early Understanding of the Non-obvious. *Cognition*, 38, 213-244.
- German, T., & Leslie, A. M. (2000). Attending to and Learning about Mental States. In P. Mitchell & K. Riggs (Eds.), *Children's Reasoning and the Mind* (pp. 229-252). Hove: Psychological Press.
- Gilbert, D. (1969). The Young Child's Awareness of Affect. *Child Development*, 39, 619-636.
- Gilhooly, K. J. (1995). *Thinking: Directed, Undirected and Creative* ( 3rd ed.). London: Academic Press.
- Gillberg, C. (1996). Autism and its Spectrum Disorders. In G. Forrest & P. Vostanis (Eds.), *ACPP Occasional Papers No. 13 Advances in the Assessment and Management of Autism* (pp. 3-6).
- Gillberg, C., & Forsell, C. (1984). Childhood Psychosis and Neuro Fibromatosis - More than a Coincidence. *Journal of Autism and Developmental Disorders*, 14, 1-9.
- Gopnik, A. (2000). Explanation as Orgasm and the Drive for Causal Knowledge: The Function, Evolution, and Phenomenology of the Theory Formation System. In F. Keil & A. R. Wilson (Eds.), *Explanation and Cognition* (pp. 299-324). London: MIT Press.
- Gopnik, A. (2001). *Do Children with Autism have Folkbiology?* Paper presented at the Society for Research in Child Development; Biennial Meeting, Minneapolis.



- Gopnik, A., & Astington, J. P. (1988). Children's Understanding of Representational Change and its Relation to the Understanding of False-Belief and the Appearance Reality Distinction. *Child Development*, 59, 26-37.
- Gopnik, A., Capps, L., & Meltzoff, A. N. (2000). Early Theories of Mind: What the Theory Theory Can Tell us about Autism. In S. Baron-Cohen & H. Tager-Flusberg & D. J. Cohen (Eds.), *Understanding Others Minds: Perspectives from Developmental Cognitive Neuroscience* (pp. 50-73). Oxford: Oxford University Press.
- Gopnik, A., & Meltzoff, A. N. (1997). *Words, Thoughts and Theories*. Massachusetts: MIT Press.
- Gopnik, A., Slaughter, V., & Meltzoff, A. N. (1994). Changing your Views: Understanding Perception as a Precursor to Understanding Belief. In C. Lewis & P. Mitchell (Eds.), *Origins of a Theory of Mind* (pp. 157-181). Hillsdale, N. J.: Erlbaum.
- Gopnik, A., & Wellman, H. M. (1994). The Theory-Theory. In L. A. Hirschfeld & S. A. Gelman (Eds.), *Mapping The Mind: Domain Specificity in Cognition and Culture* (pp. 257-293). Cambridge: Cambridge University Press.
- Goswami, U. (1998). *Cognition in Children*. Sussex, England: Psychological Press Ltd.
- Grandin, T. (1984). My Experiences as an Autistic Child. *Journal of Orthomolecular Psychiatry*, 13, 144-174.
- Hala, S., & Carpendale, J. (1997). All in the Mind: Children's Understanding of Mental Life. In S. Hala (Ed.), *The Development of Social Cognition* (pp. 189-239). East Sussex: Psychological Press.
- Hala, S., Chandler, M., & Fritz, A. S. (1991). Fledging Theories of Mind: Deception as a Marker of 3-year-olds' Understanding of False Belief. *Child Development*, 62, 83-97.
- Happe, F. (1994a). *Autism: An Introduction to Psychological Theory*. London: University College London.
- Happe, F. (1994b). An Advanced Test of Theory of Mind: Understanding of Story Characters' Thoughts and Feelings by Able Autistic, Mentally Handicapped, and Normal Children and Adults. *Journal of Autism and Developmental Disorders*, 24(2), 129-154.
- Happe, F. (1995). The Role of Age and Verbal Ability in the Theory of Mind Task Performance of Subjects with Autism. *Child Development*, 66, 843-855.
- Happe, F. (2000). Parts, Wholes, Meaning and Minds: Central Coherence and its Relation to Theory of Mind. In S. Baron-Cohen & H. Tager-Flusberg & D. Cohen (Eds.),

- Understanding Others Minds: Perspectives from Developmental Cognitive Neuroscience* (pp. 203-221). Oxford: Oxford University Press.
- Happe, F. (2001). Social and Nonsocial Development in Autism: Where are the Links? In J. A. Burack & T. Charman & N. Yirmiya & P. R. Zelazo (Eds.), *The Development of Autism: Perspectives from Theory and Research* (pp. 237 - 254). Mahwah: New Jersey: Lawrence Erlbaum Associates.
- Harris, P., Johnson, C. N., Hutton, D., Andrews, G., & Cooke, T. (1989). Young Children's Theory of Mind and Emotion. *Cognition and Emotion*, 3, 379-400.
- Hart, C. (1989). *Without Reason*. New York: Harper and Row.
- Hatano, G. (1997). Commentary: Core Domains of Thought, Innate Constraints and Sociocultural Contexts. In H. M. Wellman & K. Inagaki (Eds.), *The Emergence of Core Domains of Thought: Children's Reasoning about Physical, Psychological and Biological Phenomena*. (Vol. 75, pp. 71-79). San Francisco: Jossey Bass.
- Hatano, G., & Inagaki, K. (1994). Young Children's Naive Theory of Biology. *Cognition*, 56, 171-188.
- Heyman, G. D., & Dweck, C. S. (1998). Children's Thinking about Traits: Implications for Judgement of Self and Others. *Child Development*, 69, 391-403.
- Heyman, G. D., & Gelman, S. A. (1998). Young Children use Motive Information to Make Trait Inferences. *Developmental Psychology*, 34, 310-321.
- Hickling, A. K., & Wellman, H. M. (2001). The Emergence of Children's Causal Explanations and Theories: Evidence from Everyday Conversations. *Developmental Psychology*, 37(5), 668-683.
- Hirschfeld, L. A., & Gelman, S. A. (1994). Towards a Topography of Mind: An Introduction to Domain Specificity. In L. A. Hirschfeld & S. A. Gelman (Eds.), *Mapping The Mind: Domain Specificity in Cognition and Culture* (pp. 3-35). Cambridge: Cambridge University Press.
- Hobson, R. P. (1983). *Autism and the Development of Mind*. Hove, UK: Lawrence Erlbaum Associates.
- Hobson, R. P. (1984). Early Childhood Autism and the Question of Egocentrism. *Journal of Autism and Developmental Disorders*, 14, 85-104.
- Hobson, R. P. (1986). The Autistic Child's Appraisal of Expressions of Emotion: A Further Study. *Journal of Child Psychology and Psychiatry*, 27, 321-342.

- Hobson, R. P. (1987). Childhood Autism: A Once and Future Theory. *Medical Research Council News*, 9-10.
- Hobson, R. P. (1991). Methodological Issues for Experiments on Autistic Individuals' Perception and Understanding of Emotion. *Journal of Child Psychology and Psychiatry*, 32, 1135-1158.
- Hogrefe, G. J., Wimmer, H., & Perner, J. (1986). Ignorance versus False Belief: A Developmental Lag in Attribution of Epistemic States. *Child Development*, 57, 567-582.
- Hood, B. (1995). Gravity Rules for 2-4 year-olds. *Cognitive Development*, 10, 577-598.
- Hood, L., & Bloom, L. (1979). *What, When, and How about Why: A Longitudinal Study of Early Expressions of Causality* ( Vol. 181). Chicago: University of Chicago Press.
- Hornick, R., Risenhoover, N., & Gunner, M. R. (1987). The Effects of Maternal Positive, Neutral and Negative Affective Communications and Infant Responses to New Toys. *Child Development*, 58, 937-944.
- Howe, J. C. (1998). *Conceptual Structure in Childhood and Adolescence: The Case of Everyday Physics*. London: Routledge.
- Howe, J. C., Rodgers, C., & Tolmie, A. (1990). Physics in the Primary School: Peer Interaction and the Understanding of Floating and Sinking. *European Journal of Psychology Education*, 5, 459-475.
- Howlin, P. (1998). *Children with Autism and Aspergers Syndrome*. England: Wiley.
- Howlin, P., Baron-Cohen, S., & Hadwin, J. (1999). *Teaching Children with Autism to Mind-Read*. London: Wiley.
- Howlin, P., & Moore, A. (1997). Diagnosis in Autism. *Autism: An International Journal of Research and Practice*, 1, 135-162.
- Hughes, C. (1996). Control of Action and Thought: Normal Development and Dysfunction in Autism: A Research Note. *Journal of Child Psychology and Psychiatry*, 37, 229-235.
- Hughes, C., Adlam, A., Happe, F., Jackson, J., Taylor, A., & Caspi, A. (2000). Good Test Re-test Reliability for Standard and Advanced False Belief Tasks Across a Wide Range of Abilities. *Journal of Child Psychology and Psychiatry*, 41, 483-490.
- Hughes, C., Russell, J., & Robbins, T. R. (1994). Evidence for Executive Dysfunction in Autism. *Neuropsychologica*, 32, 477-492.
- Humphrey, N. (1986). *The Inner Eye*. London: Faber & Faber.

- Hunt, A., & Dennis, J. (1987). Psychiatric Disorder Among Children with Tuberous Sclerosis. *Developmental Medicine and Child Neurology*, 29, 190-198.
- Hutt, C., & Hutt, S. J. (1965). Effects of Environmental Complexity on Stereotypes Behaviours of Children. *Animal Behaviour*, 13, 1-4.
- Hutt, C., & Hutt, S. J. (1970). Stereotypies and their Relation to Arousal: A Study of Autistic Children. In C. Hutt & S. J. Hutt (Eds.), *Behavioural Studies in Psychiatry* (pp. 175-204). Oxford: Pergamon Press.
- Inagaki, K. (1990). The Effects of Raising Animals on Children's Biological Knowledge. *British Journal of Developmental Psychology*, 8, 119-129.
- Inagaki, K., & Hatano, G. (1993). Young Children's Understanding of the Mind-Body Distinction. *Child Development*, 64, 1534-1549.
- Inagaki, K., & Hatano, G. (2002). *Young Children's Thinking about the Biological World*. New York & Brighton: Psychology Press.
- Inhelder, B., & Piaget, J. (1958). *The Growth of Logical Thinking*. New York: Basic Books.
- Izard, C. E. (1971). *The Face of Emotion*. New York: Appleton-Century-Crofts.
- Jarrold, C., Butler, D. W., Cottington, E. M., & Jimenez, F. (2000). Linking Theory of Mind and Central Coherence Bias in Autism and in the General Population. *Developmental Psychology*, 36, 126 - 138.
- Jarrold, C., & Routh, D. A. (1997). Is There Really a Link between Engineering and Autism. *Autism: An International Journal of Research and Practice*, 1(1), 101-109.
- Johnson, M. H., & Morton, J. (1991). *Biology and Cognitive Development: The Case of Face Recognition*. Oxford: Basil Blackwell.
- Johnston, C. N., & Carey, S. (1998). Knowledge Enrichment and Conceptual Change in Folkbiology: Evidence from Williams Syndrome. *Cognitive Psychology*, 37, 156-200.
- Johnston, C. N., & Wellman, H. M. (1982). Children's Developing Conceptions of the Mind and Brain. *Child Development*, 53, 222-234.
- Jorde, R., Hasstedt, S. J., Ritvo, E. R., Mason-Brothers, A., Freeman, B. J., Pingree, C., McMahon, W. M., Peterson, B., Jenson, W. R., & Moll, A. (1991). Complex Segregation Analysis of Autism. *American Journal of Human Genetics*, 49, 932-938.
- Kail, R. (1990). *The Development of Memory in Children*. New York: Freeman.
- Kaiser, M. K., McCloskey, M., & Proffitt, D. R. (1986). Development of Intuitive Theories of Motion: Curvilinear Motion in the Absence of External Forces. *Developmental Psychology*, 22, 67-71.



- Kaiser, M. K., Proffitt, H. D. R., & McCloskey, M. (2000). The Development of Beliefs about Falling Objects. In K. Lee (Ed.), *Childhood Cognitive Development: The Essential Readings* (pp. 289-306). Oxford: Blackwell.
- Kaiser, M. K., Proffitt, D. R., & Anderson, K. (1985). Judgements of Natural and Anomalous Trajectories in the Presence and Absence of Motion. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 11, 795-803.
- Kaiser, M. K., Proffitt, H. D. R., & McCloskey, M. (1985). The Development of Beliefs about Falling Objects. *Perception and Psychophysics*, 38, 533-539.
- Kalish, W. C. (1998). Young Children's Predictions of Illness: Failure to Recognise Probabilistic Causation. *British Journal of Developmental Psychology*, 34, 1046-1058.
- Kalish, W. C. (1999). What Young Children's Understanding of Contamination and Contagion Tells us about Their Concepts of Illness. In M. Seigel & C. C. Petersen (Eds.), *Children's Understanding of Biology and Health* (pp. 99-131). Cambridge: Cambridge University Press.
- Kanner, L. (1943). Autistic Disturbances of Affective Contact. *Nervous Child*, 2, 217-250.
- Karmiloff-Smith, A. (1992). *Beyond Modularity: A Developmental Perspective on Cognitive Science*. Cambridge: MIT Press.
- Karmiloff-Smith, A. (1999). The Connectionist Infant: Would Piaget Turn in His Grave? In A. Slater & D. Muir (Eds.), *The Blackwell Reader in Developmental Psychology* (pp. 43-53). Oxford: Blackwell.
- Karmiloff-Smith, A., Johnston, H., Grant, J., Jones, J., Karmiloff, Y.-N., Bartrip, J., & Cuckle, C. (1993). From Sentential to Discourse Functions: Detection and Explanation of Speech Repairs in Children and Adults. *Discourse Processes*, 16, 565-584.
- Keil, F., & Wilson, A. R. (2000). *Explanation and Cognition*. Cambridge MA: MIT Press.
- Keil, F. C. (1981). Constraints on Knowledge and Cognitive Development. *Psychological Review*, 88(3), 197-227.
- Keil, F. C. (1991). The Emergence of Theoretical Beliefs as Constraints on Concepts. In S. Carey & R. Gelman (Eds.), *The Epigenesis of Mind: Essays on Biology and Cognition* (pp. 237-256). Hillsdale NJ: Lawrence Erlbaum Associates.
- Keil, F. C. (1994). The Birth and Nurture of Concepts by Domains: The Origins of Concepts of Living Things. In L. A. Hirschfeld & S. A. Gelman (Eds.), *Mapping the Mind: Domain Specificity in Cognition and Culture* (pp. 234-254). Cambridge: Cambridge University Press.

- Keil, F. C. (1995). The Growth of Causal Understanding of Natural Kinds. In D. Sperber & D. Premack & A. J. Premack (Eds.), *Causal Cognition: A Multidisciplinary Debate* (pp. 234-267). Oxford: Clarendon Press.
- Keil, F. C. (1999). Cognition, Content and Development. In M. Bennett (Ed.), *Developmental Psychology: Achievements and Prospects* (pp. 165-183). London: Psychological Press.
- Keil, F. C., & Silberstein, C. S. (1998). Schooling and the Acquisition of Theoretical Knowledge. In D. R. Olsen & N. Torrance (Eds.), *The Handbook of Education and Human Development: New Models of Learning, Teaching and Schooling* (pp. 621-645). Oxford: Blackwell.
- Kellman, P. J., & Spelke, E. S. (1983). Perception of Partly Occluded Objects in Infancy. *Cognitive Psychology*, 15, 483-524.
- Kim, I. K., & Spelke, E. S. (1999). Perception and Understanding of Effects of Gravity and Inertia on Object Movement. *Developmental Science*, 2(3), 339-362.
- Klin, A., Volkmar, S., Sparrow, S., Cicchetti, D., & Rourke, B. P. (1995). Validity and Neuropsychological Characterisation of Asperger Syndrome: Convergence with Nonverbal Learning Disabilities Syndrome. *Journal of Child Psychology and Psychiatry*, 36(7), 1127-1140.
- Klinnert, M. D., Campos, J. J., Sorce, J. F., Emde, R. N., & Svejda, M. (1983). Emotions as Behaviour Regulators: Social Referencing in Infancy. In R. Plutchik & H. Kellerman (Eds.), *Emotion: Theory, Research and Experience, Vol. 2 Emotions in Early Development* (pp. 57-86). New York: Academic Press.
- Kohn, A. S. (1993). Preschoolers' Reasoning about Density: Will it Float? *Child Development*, 64(1), 637-650.
- Krist, H. (2001). Development of Naive Beliefs about Moving Objects - The Straight Down Belief in Action. *Cognitive Development*, 15(3), 281-308.
- LaBarbera, J. D., Izard, C. E., Vietze, P., & Parisi, D. (1976). Four-and six-month-old Infants' Visual Response to Joy, Anger, and Neutral Expressions. *Child Development*, 47, 535-538.
- Laurendeau, M., & Pinard, A. (1962). *Causal Thinking in the Child*. New York: International Universities Press.

- Lee, K., & Homer, B. (1999). Children as Folk Psychologists: The Developing Understanding of Mind. In A. Slater & D. Muir (Eds.), *The Blackwell Reader in Developmental Psychology* (pp. 228-252). Oxford: Blackwell.
- Leekham, S. R., & Perner, J. (1991). Does the Autistic Child Have a Representational Deficit? *Cognition*, 40, 203-218.
- Leslie, A. M. (1982). The Perception of Causality in Infants. *Perception*, 11, 173-186.
- Leslie, A. M. (1984). Spatiotemporal Continuity and the Perception of Causality in Infants. *Perception*, 13, 287-305.
- Leslie, A. M. (1987). Pretense and Representations: The Origins of "Theory of Mind". *Psychological Review*, 94, 412-426.
- Leslie, A. M. (1994). ToMM, ToBY and Agency: Core Architecture and Domain Specificity. In L. A. Hirschfeld & S. A. Gelman (Eds.), *Mapping the Mind: Domain Specificity in Cognition and Culture* (pp. 169-200). Cambridge: Cambridge University Press.
- Leslie, A. M., & Frith, U. (1988). Autistic Children's Understanding of Seeing, Knowing and Believing. *British Journal of Developmental Psychology*, 6, 315-324.
- Leslie, A. M., & Keeble, S. (1987). Do Six-month-old Infants Perceive Causality? *Cognition*, 25, 265-288.
- Leslie, A. M., & Roth, D. (1993). What Autism Teaches us about Metarepresentation. In S. Baron-Cohen & H. Tager-Flusberg & D. Cohen (Eds.), *Understanding Others Minds: Perspectives From Autism* (pp. 83-111). New York: Oxford University Press.
- Leslie, A. M., & Thaiss, L. (1992). Domain Specificity in Conceptual Development: Neuropsychological Evidence from Autism. *Cognition*, 43, 225-251.
- Lewis, C., & Osbourne, A. (1990). Three-year-old's Problem with False Belief: Conceptual Deficit or Linguistic Artefact? *Child Development*(61), 1514-1519.
- Lewis, M., Stanger, C., & Sullivan, M. W. (1989). Deception in 3-year-olds. *Developmental Psychology*, 25(3), 439-443.
- Liberman, A., & Mattingly, I. (1989). A Specialisation for Speech Perception. *Science*, 243, 489-494.
- Lillard, A. S. (1993). Young Children's Conceptualization of Pretense: Action or Mental Representational States? *Child Development*, 64, 372-386.
- Limber, J. (1973). The Genesis of Complex Sentences. In T. E. Moore (Ed.), *Cognitive Development and the Acquisition of Language* (pp. 169-185). New York: Academic Press.

- Lord, C., & Rutter, M. (1994). Autism and Pervasive Developmental Disorders. In M. Rutter & E. Taylor & B. Hersov (Eds.), *Child and Adolescent Psychiatry: Modern Approaches* (3 ed., pp. 569-591). Oxford: Blackwell.
- Lord, C., & Schopler, E. (1987). Neurobiological Implications of Sex Differences in Autism. In E. Schopler & G. Mesibov (Eds.), *Neurobiological Issues in Autism* (pp. 191-211). New York: Plenum Press.
- Loveland, K. A., Pearson, D. A., Tunali-Kotoski, B., Ortegón, J., & Gibbs, M. C. (2001). Judgements of Social Appropriateness by Children and Adolescents with Autism. *Journal of Autism and Developmental Disorders*, 31(4), 367-376.
- Marr, D. (1982). *Vision*. New York: W. H. Freeman.
- Masur, E. F. (1983). Gestural Development, Dual-directional Signaling and the Transition to Words. *Journal of Psycholinguistic Results*, 12, 93-109.
- Mayes, S., Calhoun, S. L., & Crites, D. (2001). Does DSM-IV Asperger's Disorder Exist? *Journal of Abnormal Child Psychology*, 29(3), 263-271.
- McCloskey, M. (1983). Intuitive Physics. *Scientific American*, 248(4), 122-130.
- McCloskey, M., Washburn, A., & Felch, L. (1983). Intuitive Physics: The Straight Down Belief and its Origin. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 9, 636-649.
- McCune-Nicolich, L. M. (1981). Toward Symbolic Functioning: Structure of Early Use of Pretend Games and Potential Parallels with Language. *Child Development*, 52, 785-797.
- McGarrigle, J., & Donaldson, M. (1974). Conservation Accidents. *Cognition*, 3, 341-350.
- McGhee, P. E. (1979). *Humour: Its Origin and Development*. San Francisco: W. H. Freeman.
- McGregor, E., Whiten, A., & Blackburn, P. (1998). Teaching Theory of Mind by Highlighting Intention and Illustrating Thoughts. *British Journal of Developmental Psychology*, 16, 281-300.
- Medical Research Council. (2001). *Review of Autism Research: Epidemiology and Causes*. London, England: Medical Research Council.
- Meltzoff, A. N., & Gopnik, A. (1993). The Role of Imitation in Understanding Persons and Developing a Theory of Mind. In S. Baron-Cohen & H. Tager-Flusberg & D. Cohen (Eds.), *Understanding Other Minds: Perspectives from Autism* (pp. 335-366). New York: Oxford University Press.



- Meltzoff, A. N., & Moore, M. K. (1977). Imitation of Facial and Manual Gestures by Human Neonates. *Science*, 198, 75-78.
- Meltzoff, A. N., & Moore, M. K. (1983). Newborn Infants Imitate Adult Facial Gestures. *Child Development*, 54, 702 - 709.
- Meltzoff, A. N., & Moore, M. K. (1989). Imitation in Newborn Infants: Exploring the Range of Gestures Imitated and the Underlying Mechanisms. *Developmental Psychology*, 25, 954-962.
- Meltzoff, A. N., & Moore, M. K. (2000). Resolving the Debate about Early Imitation. In D. Muir & A. Slater (Eds.), *Infant Development: The Essential Readings* (pp. 176-181). Oxford: Blackwell.
- Metz. (1993). Pre-schoolers Developing Knowledge of the Pan Balance. *Cognition and Instruction*, 11, 31-93.
- Metz, K. E. (1985). The Development of Children's Problem Solving in a Gears Task: A Problem Space Perspective. *Cognitive Science*, 9, 431-471.
- Miller, P. H. (1989). *Theories of Cognitive Development*. New York: Freeman.
- Miller, P. H., & Aloise, P. A. (1989). Young Children's Understanding of the Psychological Causes of Behaviour. *Child Development*, 60, 257-285.
- Mitchell, P., & Lacohee, H. (1991). Children's Early Understanding of False Belief. *Cognition*, 39, 107-127.
- Moses, L. J. (1993). Young Children's Understanding of Belief Constraints on Intention. *Cognitive Development*, 8, 1-25.
- Mundy, P., & Crowson, M. (1997). Joint Attention and Early Social Communication. *Journal of Autism and Developmental Disorders*, 27, 653-676.
- Mundy, P., & Sigman, M. (1989). The Theoretical Implications of Joint Attention Deficits in Autism. *Developmental Psychopathology*, 1, 173-183.
- Murphy, G. L., & Medin, D. L. (1985). The Role of Theories in Conceptual Coherence. *Psychological Review*, 92, 289-316.
- Nelson, C. A. (1987). The Recognition of Facial Expressions in the First Two Years of Life: Mechanisms of Development. *Child Development*, 58, 889-909.
- Olsen, D. R., Astington, J. W., & Harris, P. L. (1988). Introduction. In J. W. Astington & P. J. Harris & D. R. Olsen (Eds.), *Developing Theories of Mind* (pp. 1-19). Cambridge: Cambridge University Press.

- Osterling, J., & Dawson, G. (1994). Early Recognition of Children with Autism: A Study of First Birthday Home Video Tapes. *Journal of Autism and Developmental Disorders*, 24, 247-257.
- Oswald, D. P., & Ollendick, T. (1989). Role Taking and Social Competence in Autism and Mental Retardation. *Journal of Autism and Developmental Disorders*, 19, 119-128.
- Ozonoff, S., Rogers, S. J., & Pennigton, B. F. (1991). Executive Function Deficits in High Functioning Autistic Individuals: Relationship to a Theory of Mind. *Journal of Child Psychology and Psychiatry*, 32, 1081-1105.
- Ozonoff, S., & Strayer, D. L. (1997). Inhibitory Function in Non-retarded Children with Autism. *Journal of Autism and Developmental Disorders*, 27, 59-77.
- Pennington, B. F., Rodgers, S. J., Bennetto, L., Griffith, E. M., Reed, D. T., & Shyu, V. (1997). Validity Tests of the Executive Dysfunction Hypothesis. In J. Russell (Ed.), *Autism as an Executive Disorder* (pp. 143-178). Oxford: Oxford University Press.
- Perner, J. (1991). *Understanding the Representational Mind*. New York: MIT Press.
- Perner, J. (1992). Grasping the Concept of Representation: Its Impact on 4-year-olds' Theory of Mind and Beyond. *Human Development*, 35(3), 146-155.
- Perner, J., & Davies, G. (1991). Understanding of the Mind as an Active Information Processor: Do Young Children Have a "Copy Theory of Mind?". *Cognition*, 39, 51-69.
- Perner, J., Frith, U., Leslie, A. M., & Leekham, S. R. (1989). Exploration of the Autistic Child's Theory of Mind: Knowledge, Belief and Communication. *Child Development*, 60, 689-700.
- Perner, J., & Lang, B. (2000). Theory of Mind and Executive Function: Is There a Developmental Relationship. In S. Baron-Cohen & H. Tager-Flusberg & D. Cohen (Eds.), *Understanding Others Minds: Perspectives from Developmental Cognitive Neuroscience* (pp. 150-181). Oxford: Oxford University Press.
- Perner, J., Leekham, S. R., & Wimmer, H. (1987). Three-year-old's Difficulty with False Belief. *British Journal of Developmental Psychology*, 5, 125-137.
- Perner, J., Stummer, S., & Lang, B. (1999). Executive Functions and Theory of Mind: Cognitive Complexity or Functional Dependence. In P. D. Zelazo & J. W. Astington & D. R. Olsen (Eds.), *Developing Theories of Intention: Social Understanding and Self Control* (pp. 133 - 152). Hillsdale, NJ: Lawrence Erlbaum Associates.

- Petersen, C. C., & Siegal, M. (1998). Changing Focus on the Representational Mind: Deaf, Autistic and Normal Children's Concepts of False Photos, False Drawings and False Beliefs. *British Journal of Developmental Psychology*, 16, 301-320.
- Petersen, C. C., & Siegel, M. (1997). Domain Specificity and Everyday Biological, Physical and Psychological Thinking in Normal, Autistic and Deaf Children. In H. Wellman & K. Inagaki (Eds.), *The Emergence of Core Domains of Thought: Children's Reasoning about Physical, Psychological and Biological Phenomena* (pp. 55-70). San Francisco: Jossey Bass.
- Phillips, W., Baron-Cohen, S., & Rutter, M. (1998). Understanding Intention in Normal Development and in Autism. *British Journal of Developmental Psychology*, 16, 337-348.
- Piaget, J. (1926). *The Language of Thought of the Child*. London: Routledge and Kegan Paul.
- Piaget, J. (1930). *The Child's Conception of Physical Causality*. London: Routledge and Kegan Paul.
- Piaget, J. (1932). *The Moral Judgement of the Child*. London: Kegan Paul, Trench Trubner.
- Piaget, J. (1952). *The Origin of Intelligence of the Child*. London: Routledge and Kegan Paul.
- Piaget, J. (1954). *The Construction of Reality in the Child*. New York: Basic Books.
- Piaget, J. (1955). *The Child's Construction of Reality*. London: Routledge and Kegan Paul.
- Piaget, J., & Inhelder, B. (1974). *The Child's Construction of Quantities*. New York: WW Norton.
- Pillow, B. H. (1989). Early Understanding of Perception as a Source of Knowledge. *Journal of Experimental Child Psychology*, 47(1), 116-129.
- Pillow, B. H. (1991). Children's Understanding of Biased Social Cognition. *Developmental Psychology*, 27, 539-551.
- Pine, K. J., & Messer, D. (2000). The Effect of Explaining Others' Actions on Children's Implicit Theories of Balance. *Cognition and Instruction*, 18, 35-51.
- Piven, J., Gayle, J., Chase, J., Fink, B., Landa, R., Wzorek, M., & Folstein, S. (1990). A Family History Study of Neuropsychiatric Disorders in the Adult Siblings of Autistic Individuals. *Journal of the American Academy of Child and Adolescent Psychiatry*, 29, 177-183.

- Pratt, C., & Bryant, P. E. (1990). Young Children Understand That Looking Leads to Knowing (as long as they are looking into a single barrel). *Child Development*, 61(4), 973-982.
- Premack, D. (1990). The Infant's Theory of Self-propelled Objects. *Cognition*, 36, 1-116.
- Prior, M. R. (1977). Psycholinguistic Disabilities of Autistic and Retarded Children. *Journal of Mental Deficiency Research*, 21, 37-45.
- Prior, M. R. (1979). Cognitive Abilities and Disabilities in Infantile Autism: A Review. *Journal of Abnormal Child Psychology*, 7, 357-380.
- Repacholi, B. M., & Gopnik, A. (1997). Early Reasoning about Desires: Evidence From 14-and 18-Month Old Infants. *Developmental Psychology*, 33, 12-21.
- Richardson, K. (1998). *Models of Cognitive Development*. Sussex: Psychological Press.
- Ricks, D., & Wing, L. (1975). Language, Communication and the Use of Symbols in Normal and Autistic Children. *Journal of Autism and Childhood Schizophrenia*, 5, 191-220.
- Rieffe, C., Terwogt, M. M., & Stockmann, L. (2000). Understanding Atypical Emotions among Children with Autism. *Journal of Autism and Developmental Disorders*, 30(3), 195-203.
- Robinson, E. J., & Mitchell, P. (1995). Masking of Children's Early Understanding of the Representational Mind: Backwards Explanation versus Prediction. *Child Development*, 66, 1022 - 1039.
- Rodrigues, D. M. A. P. (1980). Notions of Physical Laws in Childhood. *Science Education*, 64, 59-84.
- Rogers, S. J., & Pennigton, B. F. (1991). A Theoretical Approach to the Deficits in Infantile Autism. *Developmental Psychopathology*, 3, 137-162.
- Rumsey, J. M., & Hamburger, S. D. (1988). Neuropsychological Findings in High Functioning Men with Infantile Autism, Residual State. *Journal of Clinical and Experimental Neuropsychology*, 10, 201-221.
- Rumsey, J. M., & Hamburger, S. D. (1990). Neuropsychological Divergence of High Functioning Level Autism and Severe Dyslexia. *Journal of Autism and Developmental Disorders*, 20, 155-168.
- Russell, J. (1997). *Autism as an Executive Disorder*. Oxford: Oxford University Press.
- Russell, J., Mauther, N., Sharpe, S., & Tidswell, T. (1991). The Windows Task as a Measure of Strategic Deception in Pre-schoolers and Autistic Subjects. *British Journal of Developmental Psychology*, 9, 331-349.

- Russell, J., Saltmarsh, R., & Hill, E. (1999). What Do Executive Factors Contribute to the Failure on False Belief Tasks by Children with Autism. *Journal of Child Psychology and Psychiatry*, 40, 859-868.
- Rutter, M. (1985). Resilience in the Face of Adversity: Protective Factors and Resistance to Psychiatric Disorders. *British Journal of Psychiatry*, 147, 598-611.
- Sapp, F., Lee, K., & Muir, D. (1997). *Three-year-olds' Difficulty with the Appearance-Reality Distinction: Is it Apparent or Real*. Paper presented at the Society for Research in Child Development, Washington, DC.
- Savitsky, J. C., & Izard, C. E. (1970). Developmental Changes in the Use of Emotion Cues in a Concept-formation Task. *Developmental Psychology*, 3, 350-357.
- Scaife, M., & Bruner, J. (1975). The Capacity for Joint Visual Perception in the Infant. *Nature*, 253, 265-266.
- Schopler, G. M., Mesibov, G., & Kuncie, L. J. (1998). *Asperger Syndrome or High Functioning Autism?* New York: Plenum.
- Sedlack, A. J., & Kurtz, S. T. (1981). A Review of Children's Use of Causal Inference. *Child Development*, 52, 759-784.
- Shah, A., & Frith, U. (1983). An Islet of Ability in Autistic Children : A Research Note. *Journal of Child Psychology and Psychiatry*, 24, 613-620.
- Shatz, M., Wellman, H., & Silber, S. (1983). The Acquisition of Mental Verbs: A Systematic Investigation of the First Reference to Mental State. *Cognition*, 14, 301-315.
- Shultz, T. R., & Mendelson, R. (1975). The Use of Covariation as a Principle of Causal Analysis. *Child Development*, 46, 394-399.
- Shultz, T. R., Parado, S., & Altman, E. (1982). Young Children's Use of Transitive Inference in Causal Chains. *British Journal of Psychology*, 73, 235-241.
- Siegal, B. (1996a). *The World of the Autistic Child: Understanding and Treating Autistic Spectrum Disorders*. Oxford: Oxford University Press.
- Siegal, M. (1996b). Conversation and Cognition. In E. Carterette & M. Friedman (Eds.), *Handbook of Perception and Cognition: Perceptual and Cognitive Development* (2nd ed., pp. 244-282). New York: Academic Press.
- Siegal, M., & Beattie, K. (1991). Where To Look First for Children's Understanding of False Beliefs. *Cognition*, 38, 112.
- Siegler, R. (1976). Three Aspects of Cognitive Development. *Cognitive Psychology*, 8, 481-520.



- Sigman, M., Mundy, P., Sherman, T., & Ungerer, J. A. (1986). Social Interactions of Autistic, Mentally Retarded, and Normal Children and their Caregivers. *Journal of Child Psychology and Psychiatry*, 27, 647-656.
- Sigman, M., & Ungerer, J. A. (1981). Sensorimotor Skills and Language Comprehension in Autistic Children. *Journal of Abnormal Child Psychology*, 9, 149-165.
- Sigman, M., & Ungerer, J. A. (1984). Attachment Behaviours in Autistic Children. *Journal of Autism and Developmental Disorders*, 14, 231-244.
- Sigman, M., Ungerer, J. A., Mundy, P., & Sherman, T. (1987). Cognition in Autistic Children. In D. Cohen & M. Donnellan (Eds.), *Handbook of Autism and Pervasive Developmental Disorders* (pp. 103-120). New York: Wiley.
- Skinner, B. F. (1985). Cognitive Science and Behaviourism. *British Journal of Psychology*, 76, 291-301.
- Slaughter, V., & Gopnik, A. (1996). Conceptual Coherence in the Child's Theory of Mind: Training Children to Understand Belief. *Child Development*, 67, 2967-2988.
- Smalley, S. L., & Asarnow, R. F. (1990). Brief Report: Cognitive Sub-clinical Markers in Autism. *Journal of Autism and Developmental Disorders*, 20, 271-278.
- Smith, C., Carey, S., & Wiser, M. (1985). On Differentiation: A Case Study of the Development of the Concepts of Size, Weight and Density. *Cognition*, 21, 177-237.
- Sodian, B., & Frith, C. (1992). Deception and Sabotage in Autistic, Retarded and Normal Children. *Journal of Child Psychology and Psychiatry*, 33, 591-606.
- Sorce, J. F., Emde, R. N., Campos, J. J., & Klinert, N. D. (1985). Maternal Emotional Signalling: It's Effect on the Visual Cliff Behaviour of 1-year-olds. *Developmental Psychology*, 20, 195-200.
- Spelke, E. S. (1988). Where Perceiving Ends and Thinking Begins: The Apprehension of Objects in Infancy. In A. Yonas (Ed.), *Perceptual Development in Infancy. The Minnesota Symposium on Child Psychology* (Vol. 20). New Jersey: Lawrence Erlbaum Associates.
- Spelke, E. S. (1991). Physical Knowledge in Infancy: Reflections on Piaget's Theory. In S. Carey & S. A. Gelman (Eds.), *The Epigenesis of Mind* (pp. 133-171). New Jersey: Lawrence Erlbaum Associates.
- Spelke, E. S., Breinlinger, K., Macomber, J., & Jackson, K. (1992). Origins of Knowledge. *Psychological Review*, 99, 605-632.

- Spelke, E. S., Phillips, A., & Woodward, A. L. (1995). Infants Knowledge of Object Motion and Human Action. In D. Sperber & D. Premack & A. J. Premack (Eds.), *Causal Cognition: A Multidisciplinary Debate* (pp. 44-78). Oxford: Clarendon Press.
- Spelke, E. S., & Van de Walle, G. (1993). Perceiving and Reasoning about Objects: Insights from Infants. In N. Eilan & W. Brewer & R. McCarthy (Eds.), *Spatial Representation* (pp. 132-161). New York: Blackwell.
- Spelke, E. S., Von Hofsten, C., & Kestenbaum, R. (1989). Object Perception and Object Directed Reaching in Infancy: Interaction of Spatial and Kinetic Information for Object Boundaries. *Developmental Psychology*, 25, 185-196.
- Sperber, D., Premack, D., & Premack, A. J. (1995). *Causal Cognition: A Multidisciplinary Debate*. Oxford: Oxford University Press.
- Springer, K. (1999). How a Naïve Theory of Biology is Acquired. In M. Seigel & C. C. Petersen (Eds.), *Children's Understanding of Biology and Health* (pp. 45 - 71). Cambridge: Cambridge University Press.
- Stephans, J. I., Beiswenger, R. E., & Dyche, S. (1986). Misconceptions Die Hard. *The Science Teacher*, 53, 65-69.
- Stich, S. (1983). *From Folk Psychology to Cognitive Science*. Massachusetts: MIT Press.
- Stitch, S., & Nichols, S. (1995). Folk Psychology: Simulation or Tacit Theory? In M. Davis & T. Stone (Eds.), *Folk Psychology* (pp. 123-158). Oxford: Blackwell.
- Surian, L., & Leslie, A. M. (1999). Competence and Performance in False Belief Understanding: A Comparison of Autistic and Normal 3-year-old Children. *British Journal of Developmental Psychology*, 17(1), 141-155.
- Swettenham, J. G. (1996). The Early Diagnosis of Autism: Screening at 18 Months of Age. In G. Forrest & P. Vostanis (Eds.), *ACCP Occasional Papers No. 13 Advances in The Assessment and Management of Autism* (pp. 13-19).
- Szatmari, P., Tuff, L., Finlayson, M. A., & Bartolucci, G. (1990). Asperger Syndrome and Autism: Neurocognitive Aspects. *Journal of the American Academy of Child and Adolescent Psychiatry*, 29, 130-135.
- Tabachnick, B. G., & Fidell, L. S. (1996). *Using Multivariate Statistics*. New York: Harper Collins.
- Tager-Flusberg, H. (1989). *An Analysis of Discourse Ability and Internal State Lexicons in a Longitudinal Study of Autistic Children*. Paper presented at the Biennial Meeting of Society for Research in Child Development, Kansas City.

- Tager-Flusberg, H. (1993). What Language Reveals about the Understanding of the Minds in Children with Autism. In S. Baron-Cohen & H. Tager-Flusberg & D. Cohen (Eds.), *Understanding The Mind: Perspectives from Autism* (pp. 138-157). New York: Oxford University Press.
- Tager-Flusberg, H., & Sullivan, K. (1994). Predicting and Explaining Behaviour: A Comparison of Autistic, Mentally Retarded and Normal Children. *Journal of Child Psychology and Psychiatry and Applied Disciplines*, 35(6), 1059-1075.
- Tager-Flusberg, H., & Sullivan, K. (2000). A Componential View of Theory of Mind: Evidence From William's Syndrome. *Cognition*, 76(1), 58 - 89.
- Tan, J., & Harris, P. (1991). Autistic Children Understand Seeing and Wanting. *Development and Psychopathology*, 3, 163-174.
- Tinbergen, N., & Tinbergen, E. A. (1983). *'Autistic' Children: New Hope for a Cure*. London: Allen and Unwin.
- Trevarthen, C., Aitken, K., Papoudi, D., & Robarts, J. (1996). *Children with Autism: Diagnosis and Interventions to Meet Their Needs*. London: JKP.
- Trevarthen, C., & Hubley, P. (1978). Secondary Intersubjectivity: Confidence, Confiding and Acts of Meaning in the First Year. In A. Lock (Ed.), *Action, Gesture and Symbol: The Emergence of Language* (pp. 183-229). New York: Academic Press.
- Tsai, L. Y. (1999). Recent Neurological Research in Autism. In D. B. Zager (Ed.), *Autism: Identification, Education and Treatment* (pp. 63-95). New Jersey & London: Lawrence Erlbaum Associates.
- Twigger, D., Byard, M., Driver, R., Draper, S., Hartley, R., Hennessay, S., Mohamed, R., O' Malley, C., O'Shea, T., & Scanlon, E. (1994). The Conception of Force and Motion of Students Aged Between 10 and 15 Years: An Interview Study Designed to Guide Instruction. *International Journal of Science Education*, 16, 215 - 229.
- Ungerer, J. A., & Sigman, M. (1981). Symbolic Play and Language Comprehension in Autistic Children. *Journal of the American Academy of Child and Adolescent Psychiatry*, 20, 318-337.
- Vera, A. H., & Simon, H. A. (1994). Reply to Touretzky and Pomerleau: Reconstructing Physical Symbol Systems. *Cognitive Science*, 18, 355-360.
- Volkmar, F. R. (1985). Social Development. In D. Cohen & A. M. Donellan (Eds.), *Handbook of Autism and Pervasive Developmental Disorders* (pp. 41-60). New York: Wiley.

- Vosniadou, S., & Ionnides, C. (1998). From Conceptual Development to Science Education: A Psychological Point of View. *International Journal of Science Education*, 20(10), 1213-1230.
- Walden, T. A., & Ogan, T. A. (1988). The Development of Social Referencing. *Child Development*, 59, 1230-1240.
- Walker- Andrews, A. S. (1997). Infants Perception of Expressive Behaviours: Differentiation of Multimodal Information. *Psychological Bulletin*, 121, 437-456.
- Wechsler, D. (1990). *Wechsler Pre-school and Primary Scale of Intelligence: Revised United Kingdom Edition (WIPPSI-R-UK)*. London: The Psychological Corporation.
- Wechsler, D. (1992). *Wechsler Intelligence Scale for Children: Third United Kingdom Edition (WASI-III-UK)*. London: The Psychological Corporation.
- Wechsler, D. (2000). *Wechsler Abbreviated Scale of Intelligence (WASI)*. London: The Psychological Corporation.
- Weeks, S. J., & Hobson, R. P. (1987). The Salience of Facial Expression for Autistic Children. *Journal of Child Psychology and Psychiatry*, 28(1), 137-152.
- Wellman, H. (1990). *The Child's Theory of Mind*. Cambridge MA: MIT Press.
- Wellman, H., & Estes, D. (1986). Early Understanding of Mental Entities: A Re-examination of Childhood Realism. *Child Development*, 57, 910-923.
- Wellman, H., & Gelman, S. A. (1988). Children's Understanding of the Non-obvious. In R. J. Sternberg (Ed.), *Advances in the Psychology of Human Intelligence* (Vol. 4, pp. 99-135). Hillsdale NJ: Lawrence Erlbaum Associates.
- Wellman, H., & Gelman, S. A. (1992). Cognitive Development: Foundational Theories and Core Domains. *Annual Review of Psychology*, 43, 337-375.
- Wellman, H., Hickling, A. K., & Schultz, C. A. (1997). Young Children's Psychological, Physical and Biological Explanations. In H. Wellman & K. Inagaki (Eds.), *The Emergence of Core Domains of Thought: Children's Reasoning about Physical, Psychological and Biological Phenomena. New Directions for Child Development* (Vol. 75, pp. 7-26). San Francisco: Jossey Bass.
- Wellman, H., Hickling, A. K., & Shultz, T. R. (2000). Young Children's Psychological, Physical and Biological Explanations. In K. Lee (Ed.), *Childhood Cognitive Development: The Essential Readings* (pp. 265-288). Oxford: Blackwell.

- Wellman, H., & Inagaki, K. (1997a). *The Emergence of Core Domains of Thought: Children's Reasoning about Physical, Psychological and Biological Phenomena. New Directions for Child Development* ( Vol. 75). San Francisco: Jossey Bass.
- Wellman, H., & Inagaki, K. (1997b). Editors notes. In H. Wellman & K. Inagaki (Eds.), *The Emergence of Core Domains of Thought: Children's Reasoning about Physical, Psychological and Biological Phenomena* (pp. 1-5). San Francisco: Jossey Bass.
- Wellman, H., & Lagattuta, K. H. (2000). Developing Understandings of Mind. In S. Baron-Cohen & H. Tager-Flusberg & D. Cohen (Eds.), *Understanding Others Minds: Perspectives from Developmental Cognitive Neuroscience* (pp. 21-49). Oxford: Oxford University Press.
- Wellman, H., Phillips, A., & Rodriguez, T. (2000). Young Children's Understanding of Perception, Desire and Emotion. *Child Development*, 71(4), 895-912.
- Wellman, H. M., & Hicking, A. K. (1994). The Mind's 'I': Children's Conception of the Mind as an Active Agent. *Child Development*, 65, 1564-1580.
- Wellman, H. M., & Wooley, J. D. (1990). From Simple Desires to Ordinary Beliefs: The Early Everyday Development of Everyday Psychology. *Cognition*, 35, 245-275.
- Wilkening, F., & Anderson, N. H. (1991). Representation and Diagnosis of Knowledge Structures in Developmental Psychology. In N. H. Anderson (Ed.), *Contributions to Information Integration Theory: Vol. III* (pp. 43 - 80). Hillsdale NJ: Lawrence Erlbaum Associates.
- Williams, E., Costall, A., & Reddy, V. (1999). Children with Autism Experience Problems with Both Objects and People. *Journal of Autism and Developmental Disorders*, 29(5), 367-378.
- Williams, J. M., & Binnie, L. M. (2002). Children's Concepts of Illness: An Intervention to Improve Knowledge. *British Journal of Health Psychology*, 7, 129-147.
- Williams, J. M., & Tolmie, A. (2000). Conceptual Change in Biology: Group Interaction and the Understanding of Inheritance. *British Journal of Developmental Psychology*, 18, 625-649.
- Wimmer, H., & Perner, J. (1983). Beliefs about Beliefs: Representation and Constraining Function of Wrong Beliefs in Young Children's Understanding of Deception. *Cognition*, 13, 103-128.
- Wing, L. (1969). The Handicaps of Autistic Children - A Comparative Study. *Journal of Child Psychology and Psychiatry*, 10, 1-23.



- Wing, L. (1981). Asperger's Syndrome: A Clinical Account. *Psychological Medicine*, 11, 115 - 129.
- Wing, L. (1998). The History of Asperger Syndrome. In S. Schopler & G. M. Mesibov & L. J. Kunc (Eds.), *Asperger Syndrome or High Functioning Autism* (pp. 11-28). New York: Plenum.
- Wing, L. (2000). Past and Future of Research on Asperger Syndrome. In A. Klin & F. R. Volkmar & S. S. Sparrow (Eds.), *Asperger Syndrome* (pp. 418-433). New York: Guilford Press.
- Wing, L., & Gould, J. (1978). Systematic Recording of Behaviours and Skills of Retarded and Psychotic Children. *Journal of Autism and Childhood Schizophrenia*, 8, 79-97.
- Wishart, J. (1996a). Avoidant Learning Styles and Cognitive Development in Young Children. In B. Stratford & P. Gunn (Eds.), *New Approaches to Down Syndrome* (pp. 173-205). London: Cassell.
- Wishart, J. G. (1996b). Learning in Down's Syndrome: Developmental Trends. In J. A. Rondal & J. Perera & L. Nadel & A. Comblain (Eds.), *Down Syndrome: Psychological, Psychobiological and Socio-educational Perspectives* (pp. 81-96). London: Whurr.
- World Health Organisation. (1993). *International Classification of Diseases* (10 ed.). Geneva, Switzerland: World Health Organisation.
- Wulff, S. B. (1985). The Symbolic and Object Play of Children with Autism: A Review. *Journal of Autism and Developmental Disorders*, 15, 139-148.
- Xu, F., & Carey, S. (1992). Infants Metaphysics: The Case for Numerical Identity. *Cognitive Psychology*, 30, 111-153.
- Yirmiya, N., Erel, O., Shaked, M., & Solomonica-Levi, D. (1998). The Ability to Manipulate Behaviour and to Understand Manipulation of Beliefs: A Comparison of Individuals with Autism, Mental Retardation and Normal Development. *Child Development*, 32, 62-69.
- Yirmiya, N., Solomonica-Levi, D., Shulman, C., & Pilowsky, T. (1996). Theory of Mind Abilities in Individuals with Autism, Down Syndrome and Mental Retardation of Unknown Etiology: The Role of Age and Intelligence. *Journal of Child Psychology and Psychiatry*, 37, 1003-1014.
- Young-Browne, G., Rosenfeld, H. M., & Horowitz, F. D. (1977). Infant Discrimination of Facial Expressions. *Child Development*, 48, 555-562.

- Zaitchik, D. (1990). When Representations Conflict with Reality: The Pre-schoolers Problem with False Belief and False Photographs. *Cognition*, 35, 41-68.
- Zelazo, P. D., Burack, J. A., Benedetto, E., & Frye, D. (1996). Theory of Mind and Rule Use in Individuals with Down Syndrome: A Test of Uniqueness and Specificity Claims. *Journal of Child Psychology and Psychiatry*, 37, 479-484.
- Zelazo, P. R., Burack, J. A., Boseovski, J. J., Jacques, S., & Frye, D. (2001). A Cognitive Complexity and Control Framework for the Study of Autism. In J. A. Burack & T. Charman & N. Yirmiya & P. R. Zelazo (Eds.), *The Development of Autism: Perspectives From Theory and Research* (pp. 195 - 218). Mahwah: New Jersey: Lawrence Erlbaum Associates.